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EFFECTS OF NOISE OF OFFSHORE OIL AND GAS OPERATIONS ON MARINE MAMMALS — AN INTRODUCTORY ASSESSMENT

RS Gales

September 1982

Research report: 1980—1981
Prepared for the Bureau of Land Management, Department of Interior

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ADMINISTRATIVE INFORMATION

The work described in this report was conducted in 1980 and 1981 for the Bureau of Land Management (BLM) of the U.S. Department of Interior under Interagency Agreement No. AA851-IA0-5 entitled, "Study of the Effects of Sound on Marine Mammals: (NOSC Project 513-MM28). The work was sponsored by the New York Outer Continental Shelf office of BLM under the general supervision of J. Philip Thomas and Eiji Imamura. Jeffery P Petrion of BLM Code 851 served as contracting officer. This research was performed by the Naval Ocean Systems Center (NOSC). Computer Sciences Corporation (CSC) provided services under contract to NOSC. The work was done by the task group managed by Dr. Elek Lindner of the NOSC Marine Sciences Division. Principal members of the task team were: R.S. Gales, Acoustics, J.A. Hoke, Instrumentation, and D.R. Schmidt, Data Recording and Analysis. Participants from CSC were: Alma Church, Head Bio Science and Surface Surveillance Section, D. MacCormack, and R. Christensen, who performed the source spectrum analysis.

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The effects of noise from offshore oil and gas operations on marine mammals were assessed by a multifaceted study. The literature was surveyed for available data on noise from oil platforms and on hearing capabilities of marine mammals. Data on animal behavior around the platforms were collected by field observations and interviews. The noise from platforms was measured at various geographical locations and analyzed in the laboratory. Evaluation of the combined data indicates that certain platforms are relatively quiet, and therefore platforms with minimal sound emission can be designed. The highest level components of the noise from oil plat-

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forms are below 100 Hz. The distances at which large whales can detect such noise were estimated for various geographical locations. It is unlikely that platform noise will interfere with echolocation of marine mammals, and according to anecdotal information, whales ignore or easily avoid the platforms.

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SUMMARY

Because of the potential importance of noise and vibration from offshore oil and gas operations on the environment and ecology, this study was conducted for the Bureau of Land Management (BLM) of the U.S. Department of Interior during 1980 and 1981. The oil and gas resources of the outer continental shelf (OCS) are an important element of the energy plan of the USA, yet the development of these resources must be accomplished with minimum adverse effects on the marine environment. The ultimate objective of this project was to describe the behavior of the various species of marine mammals in response to the various noises produced by the OCS oil and gas operations. The program was designed to assess (1) the physical characteristics of the noise emitted by various OCS sources and (2) the response characteristics of the receiving animals, including their sound production and hearing, and behavior associated with sounds.

The approach consisted of the following elements. (1) Literature survey to collect available data on noise associated with OCS oil and gas operations and sound-related behavior of marine mammals, including sound production and hearing capabilities. (2) Field observation of animal behavior in the vicinity of OCS oil drilling and production platforms accomplished by direct observation and by interviews with platform personnel followed up by displaying marine mammal identification charts and sighting cards to be filled out and mailed to NOSC by the platform personnel. (3) Field surveys of OCS activities to record and measure underwater noise associated with the various operations of 18 representative OCS oil and gas drilling and production platforms in the Santa Barbara Channel and Middle Atlantic and Alaska coastal areas. (4) Laboratory analysis of OCS sounds recorded on magnetic tape during the field surveys to assess spectral content, source level, and duration. (5) Evaluation of the results of the previous four project elements employing analytical models to (a) predict possible animal reactions based on hearing the noise, (b)

predict the masking effect of the noise on animal acoustic communication and echolocation, and (c) recommend mitigating measures to reduce the undesirable effects , noise if it appears to be necessary.

The project resulted in the following conclusions. (1) Oil and gas platforms produce significant underwater noise over a wide range of frequencies. The highest level components are below 100 Hz. (2) The platforms measured produce less noise than the cavitating propellers of supply boats. (3) Certain platforms were relatively quiet during combined drilling and production operation, suggesting that platforms can be designed and constructed for reduced sound emission. (4) Probable auditory detection ranges of mysticete whales indicate that the low-frequency line components of platform noises may be detected at the order of hundreds of miles under low ambient noise conditions and excellent sound propagation. However, under conditions representative of the Lower Cook Inlet, Alaska; Southern California; and the Middle Atlantic areas selected for study, the more likely ranges are 3500, 1500, and 150 yards, respectively. (5) It is unlikely that platform noise will interfere with echolocation by marine mammals, and it is expected to interfere with certain other acoustic communication signals only very close to the platform. (6) Anecdotal information indicates that whales either ignore or easily avoid the platforms without appreciable change in behavior. It is important to note that this is based on observations in the Southern California and Cook Inlet areas where whales have a long history of exposure to noise of ships. It may, or may not be true of places such as the Beaufort Sea, where the whales have a very different noise exposure history.

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A. First Summary Report on BLM Project. Part A. Literature Review on Underwater Noise from Offshore Oil Operations and Underwater Hearing and Sound Production of Marine Mammals. Prepared by Charles W. Turl and edited by Elek Lindner, NOSC, June 1980.

B. "Interview Program to Determine Proximity of Large Marine Mammals to Oil/Gas Platforms," Chambers Consultants and Planners, March 1981.

C. "Survey of the Effects of Outer Continental Shelf Platforms on Cetacean Behavior," Computer Sciences Corporation, Susan McCarty, September 1981.

D. First Summary Report on BLM Project, Part B, "Field Measurements of Underwater Noise from Offshore Oil Operations," David R. Schmidt, NOSC, June 1980.

E. Second Summary Report on BLM Project, "Study of the Effects of Sound on Marine Mammals," R.S. Gales, NOSC, September 1980.

F. "Underwater Noise Measured at Fourteen Oil Platforms off Santa Barbara, California," Computer Sciences Corporation, R.S. Gales, August 1981.

G. Third Summary Report on BLM Project, "Estimated Underwater Detection Ranges by Marine Mammals of Noise from Oil and Gas Platforms," R.S. Gales, NOSC, July 1981.

H. "Possible Effects of Noise from Offshore Oil and Gas Drilling Activities on Marine Mammals: A Survey of the Literature," C.W. Turl, NOSC, September 1981.

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*These appendices constitute Volume 2 of this report

I. INTRODUCTION

The oil and gas resources of the outer continental shelf (OCS) are an important element of the energy plan of the United States, yet the development of these resources must be accomplished with a minimum of adverse effects on the coastal environment. High on the list of environmental concerns is the well-being of the oceanic animals, which comprise important elements in the coastal ecology.

Of the several agents which might impinge adversely on oceanic animal life, noise is a potential pollutant which has to date received very little attention. Noise and vibration from offshore installations may be transmitted into the sea and sea floor, and may propagate for long distances in the underwater environment. It is known that underwater sound is important to many marine organisms, particularly marine mammals, such as cetaceans (Tavolga, 1964; Myrberg, 1978). Therefore, it is vitally important that a systematic study be made of the sounds radiated by OCS operations and of their possible effects on marine animals.

Recognizing the potential importance of noise and vibration from offshore oil and gas operations on the offshore environment and ecology, the Bureau of Land Management in early 1980 tasked the Naval Ocean Systems Center to study the noise associated with oil and gas operations and to relate it to the behavior of marine mammals. Marine mammals were specified because of their known uses of underwater sound (Herman, 1980) and likely sensitivity to acoustic disturbance. This report is a brief initial look at this problem. It consists of a review of the existing literature and presents new data on observations of animals, and measurements of underwater noise in the vicinity of OCS oil and gas platforms. The report also discusses propagation of sound in the ocean and considers potential interaction of the sounds with certain marine animals.

The ultimate objective of this project is to describe the behavior of marine animals in response to the various noises produced by the OCS oil and gas operations. This is a difficult goal, ultimately requiring comprehensive observations of behavior of many animals in the presence of many types and levels of noise. Such observations would need to be made for long periods of time in order to determine whether observed changes in behavior were temporary and whether the animals readily adapt to the noise with no sustained adverse effects. Furthermore, to predict a substantial adverse effect on a species, one must determine whether such effect is deleterious to the existence of the species or to its ecological interactions. Even a sustained effect of the noise, such as denying a favored habitat might simply displace the animals by a mile or two, with no serious adverse consequences.

In view of the very small size of the data base of direct behavioral observations of the type mentioned above, this study emphasizes an alternative approach, which uses the "source-path-receiver model." In this approach, the underwater noise is measured at a known distance from the oil platform (or other noise source) a sound propagation path is assumed, and the sound pressure level is calculated for various distances from the source. These data are then combined with information on the hearing and vocal capabilities of various marine animals to calculate the following: (1) the maximum expected distance at which the sound emitted from the OCS source may be expected to be audible to this animal under various assumed background noise conditions (related to weather and oceanography), and (2) the interfering effects of the noise of the OCS source in masking the communication and echolocation signals of the animals. The first type of calculation provides initial guidelines of maximum expected ranges of influence, the implicit assumption being that if the animal is unable to hear the sound, the animal will be unaffected by it. It must be pointed out that the fact that the animal is able to hear the sound (at ranges shorter than the detection range) does not assure a reaction. In fact, it is likely that unless the sound has an extremely

threatening meaning to the animal, overt responses to the sound may not occur until its level is substantially above the threshold of detectability. The need for actual observational data on responses of the animals to various OCS oil and gas platform-related sounds must be reiterated here. Although the type of response to be expected from animals within the maximum detection range is highly uncertain, the expectation of zero influence at distances beyond this range may be a very useful consideration in environmental planning. The relevance of the second type of calculation, dealing with noise masking of the animals' own signals, to the well-being of the animals is clear. It must be noted, however, that data on animal signal source levels and directivity as well as hearing sensitivity and directivity are important to these calculations. Lack of accurate data for many species limits the usefulness of this type of calculation in many cases.

II. OBJECTIVES

The study program was designed to assess the noise-effect problem from both of the basic standpoints: (1) The physical characteristics of the noise emitted by various sources, and (2) the response characteristics of the receiving animals, including their sound production and hearing, and behavior associated with sounds. To accomplish this, the following five objectives were stated in the task assignment:

1. To determine and characterize the various sounds emitted from OCS oil and gas operations (exploration, development, and production) and from related vessel traffic.
2. To characterize the sounds emitted and perceived by various cetaceans species.
3. To evaluate the sound spectra created by human activities which could disrupt the behavior of cetaceans.
4. To determine the effects of a physical structure, such as a platform, on cetacean behavior.

5. To propose a range of mitigating measures which would eliminate or minimize the impact of sounds, offshore physical structures and associated human activities on cetaceans.

III. APPROACH

To accomplish the objectives the research plan consisted of the following five elements, each of which will be addressed in this report.

1. Literature Survey. This is a comprehensive survey of the scientific and technical literature dealing with noise associated with OCS oil and gas operations; and sound-related behavior of marine mammals, including sound production and hearing capabilities.

2. Field Observation of Animal Behavior. This consists of data on direct observation of animal behavior in the vicinity of OCS operations, such as oil and gas drilling and production platforms. This was accomplished by field teams employing specially developed interview forms, questionnaires, and animal identification charts with sighting cards designed to be filled out by personnel at the OCS sites.

3. Field Surveys of OCS Activities. This consists of on-site visits to 18 representative OCS oil and gas drilling and production platforms, and recording and measurement of underwater noise associated with various operations.

4. Laboratory Analysis of OCS Sounds. Field data, principally magnetic tape recordings, were analyzed in the laboratory for spectral content, source level, and duration.

5. Prediction of Effects of Noise on Cetaceans. Analytic models employing data on sound source levels, propagation in the sea, and reception by representative cetaceans are used to predict the distances to which effects might be expected. Effects addressed by this modeling

technique include: (1) possible animal reactions based on hearing the noise, and (2) the masking effect of the noise on animal acoustic communication and echo location.

IV. RESULTS

The results of the study program will be presented in a series of subsections, roughly paralleling the several types of effort described in the approach. Many of the findings have already been published in the form of Summary Reports (Refs. 1, 2, 3). These results are summarized briefly in this section, and the summary reports are included as Appendices A, D, E and G.

A. Literature Survey - I. Noise from Offshore Oil Operations (Ref. 1 and Appendix A). The survey indicates that published data related to offshore oil and gas operations are very limited. Four references cited provide some information on source levels and spectra of: (1) drilling operations on a man-made gravel island and a natural barrier beach island in the Prudhoe Bay area of the Beaufort Sea, (2) construction operations at two artificial islands in the Beaufort Sea (noise sources include a suction dredge, tugs, crew boats, and a clamshell shovel), and (3) a semi-submersible drilling platform in the North Atlantic. The data are reviewed in Appendix A. In general, the data show the noise to cover a broad frequency range of 10 to 10,000 Hz, with source levels between 130 and 180 dB re 1 μPa at one meter. Major tonal components are below 1000 Hz with major energy below 200 Hz. These agree in general with NOSC field measurements described in section IV C of this report. A number of significant contributions to the literature have been published since the initial literature survey (Ref. (1)) was completed, and are included in the list of references for this report. These recent reports expand the data base to cover a wider range of operations, localities, and oceanographic conditions, but do not alter the general findings of Ref. (1) regarding radiated underwater noise levels and frequency content.

Literature Survey - II. Underwater Hearing and Sound Production of Marine Mammals (Ref. 1, Appendix A). The literature search was quite productive, yielding over 80 references dealing with sound production of seven species of odontocetes and six species of mysticete whales, and hearing of nine species of odontocetes (dolphins and porpoises) and five species of pinnipeds. These data are summarized in Table 1-5 in Appendix A. It should be noted that no data are available on hearing of the large whales. This is a serious deficiency in data needed for understanding the behavior of whales in the presence of noise. Inasmuch as considerable data are available on the sounds produced by the large whales, estimates of the frequency region of whale hearing have been made by postulating that the frequency region of hearing for a whale species matches the frequency region of sounds produced by the species.

The information compiled in Appendix A was supplemented with more recently published data in Appendix H. An effort was made to estimate the possible effects of noise on marine mammals, but no positive conclusion could be drawn without conducting actual experiments under controlled conditions. A number of recommendations are presented to aid future work in predicting possible effects of noise from OCS operations on marine mammals.

B. Field Observations of Animal Behavior. The effort to obtain systematic data on behavior of marine animals in the vicinity of OCS oil and gas platforms consisted of the following:

1. Pictorial identification posters were prepared for three classes of marine mammals of interest (a) Large and Medium Whales, (b) Dolphins, Porpoises, and Small Whales, (c) Seals and Sea Lions. These charts are reproduced in Figures 1, 2, and 3. They were posted aboard oil platforms, supply boats, and other locations where they provided information to assist oil company and support activity personnel in identifying animal sightings. These posters were well-received, and

were considered helpful both for species identification and as a reminder to personnel to be alert to sight animals in the vicinity.

2. Sighting cards were distributed to certain platform and support personnel to be filled out as soon as possible by the individual after each animal sighting. It was believed that this approach would tend to reduce the subjective uncertainties associated wth memory fade during the data taking. Unfortunately the work pressures and other distractions inherent to offshore oil operations resulted in a total of only 44 filled-out cards being returned (10 from the Southern California pilot study, 11 from a second Southern California study on 9 platforms and associated work boats, and 23 from platforms in upper Cook Inlet, Alaska). The results are described by McCarty (1981). The small return from the sighting card program was a disappointment. The original intent of the card design was to use computer processing on what was expected to be a large, statistically reliable data base. This was not achieved. The data from this medium, because of the small numbers, are not considered more reliable than that from the interview program.

3. Interviews were conducted by experienced personnel, using a structured set of questions similar to those of the sighting cards. The interviews were designed to gather as systematically as possible data from the memory of platform and support personnel on past sightings of animals. The interview program consists of three parts: (1) The initial Pilot Study, conducted by Chambers Consultants and Planners (CCP) and Computer Sciences Corporation (CSC) on three Southern California platforms; (2) a study by CSC of 9 additional So. Calif. platforms and certain associated workboat personnel; and (3) a study by CSC of eight platforms in the upper Cook Inlet, Alaska area.

The two Southern California studies interviewed 30 persons each. The results are described in McCarty (1981) (Appendix C). In general, all persons reported seeing some animals; however, since the observers were not well trained, they generally could not provide much information on

species, distance, direction, and behavior of the animals. Only four out of the second thirty persons interviewed indicated that they observed any relationship between animal behavior and platform activity. Ten of the thirty, however, stated that the animals seemed to approach closer when there was less noise, but did not seem to be avoiding or driven away from the platforms when they were noisy.

The Alaska interview studies are also described by McCarty (1981) (Appendix C). The interviews were conducted on eight production platforms in upper Cook Inlet during July and August 1981. Two of these Platforms (FP-1 and FP-2) were the subjects of underwater noise recordings and measurements in June 1980, and were rated as moderately noisy on the basis of those measurements. One hundred forty six interviews were conducted, including five with helicopter pilots and the remainder with platform workers. All 146 persons reported sightings of beluga whales, some reported as close as 30 feet from the platform. Mother-calf pairs were reported in 83% of the sightings.

Responses to questions about the possible effects of the rigs on the whales were always negative. Whales are seen very close to the platform, and there were many reports that the flare booms seem to attract whales. (It is more likely that the flares attract salmon, which in turn attract the belugas.) People who had been on rigs both actively drilling and not drilling could not report any change in the numbers of whales sighted. Their observations were that as long as the noise was consistent it didn't seem to affect the whales. Change in behavior such as a quick dive, an avoidance reaction, occurred when a helicopter flew over. All of the pilots and many workers reported this response from the belugas. The direction of the tidal flow and the presence or absence of salmon seemed to be the major factors which determined the location of the beluga whales. The many reported sightings of belugas is expected in view of their known resident population in Cook Inlet. It is not known whether any changes in the population or its distribution have occurred during the period of

industrial development in the area following the discovery of natural gas in 1957. Many (78 people, 55%) reported several occasions when belugas could be seen from one side of the inlet to the other. Estimates of actual numbers range from 500-1000 animals, which may indicate that the Cook Inlet is on the beluga migration pathway. However, some kind of tagging or marker identification is needed to distinguish new groups of animals from those already counted.

Sightings of marine mammals other than belugas were few and far between. A minke whale was sighted by two people. It was about 1/2 mile away from the platform. Pilot whales were reported by seven people, all from the same platform. There were three or four animals about a mile away from the platform. There were two reported incidents of killer whales in the Cook Inlet. Five people could recall a time three years ago when a pod of five animals was seen daily for about a week. The other sightings were this past spring. Seventeen people reported seeing a pod of eight killer whales swimming within the inlet.

There were two reports of dolphins. Two workers on one platform reported a school of dolphins (50-100 members) about 1/2 mile from the platform. The second report, by three observers noted a pair of dolphins about 50 yards away from the platform.

Five people reported walrus, but all five probably saw the same animal since the reports were all from two adjacent platforms. Thirty-five individuals reported seeing seals or sea lions. Usually these animals were alone, although occasionally they appeared in pairs. The seals came in close to the platform but did not stay in the area for any length of time. Two individuals reported seeing a sea otter.

Twenty-three sighting cards were received by mail after the interviews. One card described sighting of a sea otter. It was seen around the Anchor Point area which is the lower Cook Inlet area, and

therefore not directly usable in this study. Many species of animals were seen in the lower Cook Inlet, around Anchor Point, but these animals do not usually move far enough up the Cook Inlet to be seen by the oil industry personnel on the rigs.The twenty-two cards reported beluga whales in the range of two to a thousand animals. Eleven reported 20 or less belugas, three cards reported between 20 and 50, six cards recorded 50-200, and the last two cards estimated the animals to number around a thousand. The estimated distance of the whales from the platforms ranged from 30 feet to "the other side of the inlet" with most reports at 150-300 yards. Two of these cards had pictures of beluga whales attached. No unusual behavior was reported.

C. Field Recordings and Noise Measurements

1. Description of Field Trips. Five field trips were made to gather magnetic tape recordings and operational data on noise and its sources from eighteen oil and gas platforms engaged in drilling and/or production operations. Recorded data were obtained on three general classes of platforms: (1) semi-submersible drilling platforms, (2) fixed multi-legged drilling and/or production platforms, and (3) a man-made island (production). Listed in order of occurrence, the field sites were: (1) Santa Barbara, Calif., (2) Upper Cook Inlet, Alaska, (3) Baltimore Canyon, off New Jersey, (4) Santa Barbara, Calif., and (5) Santa Barbara-Carpenteria, Calif. Table I lists all platforms on which noise data were recorded and gives a general description of each with an associated letter code which will be used to designate individual platforms. The first and second field trips are described in Appendix D. Trip 1 to the Santa Barbara area used an interim tape recorder-hydrophone system with marginal sensitivity to record the moderate levels of noise indicated by the two platforms tested. Good recordings of these two platforms were obtained in a repeat trip (trip no. 4) which used the high sensitivity recording system described in Appendix C. This high quality system was used in all trips except trip 1, and provided excellent data over a frequency band from 1 Hz to 30

KHz. Recordings and data from the three platforms in the Cook Inlet, Alaska area obtained during field trip 2 were thoroughly analyzed (Appendices D and E) and served as a principal supplier of source level information for initial analytic modeling to provide estimates of ranges at which baleen whales might be expected to hear the sounds radiated by the platforms (Appendix G). In addition to the magnetic tape recordings described above, which were essentially spot samples of noise during a few relatively short periods of aproximately five to sixty minutes each, a continuous monitor system was operated for a period of five days on platform FD-1 off Santa Barbara, Calif. This system consisted of a hydrophone, pre-amplifier-filter, and graphic level recorder which provided a continuous chart record of the overall sound pressure level. The level recorder was operated at a chart speed of 10 centimeters per hour which provided sufficient time resolution to see changes in level which lasted about 5 seconds or more. The hydrophone was suspended from the edge of the platform and lowered to a depth of 30 feet. The system was activated at 1020 hours on Monday, 19 January 1981 and operated continuously until Friday, 23 January, at approximately 1500 hours. Platform FD-1 is located in approximately 850 feet of water, and was engaged in drilling operations. Platform power is generated by large diesel engines.

In general, the underwater sound level was quite steady, except for occasional increases which appeared to be related to activity of nearby work boats. Noise associated wih the arrival and departure of the supply boats, and maneuvering by work boats near the platform produced increases of 20 to 30 decibels in the overall underwater sound level. Some noise appears to be associated with water splashing as large swells and waves interacted with the platform structure. This is based on the observation that the minimum sound levels generally occurred in the midnight to early morning period, when it may be assumed that wind and sea conditions were relatively calm. The observation that in the absence of work boats the noise during higher sea state conditions (two- to four-foot waves) only rose a few decibels indicates that the

underwater noise level at the hydrophone position under the edge of the platform was dominated by platform noise, but that it is close enough to the level of the sea noise that the total noise is slightly sea-state dependent. This is supported by a separate set of data reported in the next section.

2. Noise Sources and Acoustic Characteristics. Underwater noise associated with offshore petroleum-related operations may be generated by many types of sources and may have a wide variety of acoustic characteristics. This section will address briefly both sources and characteristics.

(a) Noise sources

(1) Offshore platform. This is a most obvious source, because of the high mechanical power expended during both drilling and production operations, and the relative permanence of the platform. Field recordings and measurements reported in this study are directed principally at offshore platforms because of the scarcity of data on such sources. Noise radiated by a platform may be expected to depend on many factors, such as size and shape of its underwater surfaces, construction materials, structural configuration, structural bonding and damping, type of machinery and power, machinery balancing, machinery coupling to structure, machinery operating speeds, muffling of engine exhausts, etc. Environmental factors which influence noise radiation include water depth and bottom type. It is apparent that an assessment of noise radiation from platforms will require measurements from a large number of different platforms with various machinery combinations and located in various environments in order to achieve a reliable data base. Platforms sampled in this study to date are listed in Table I, which shows location, type, activity, prime power source, and activity at time of recording. Types of platforms not sampled are drill ships, jack-up rigs, and monopods (single large cylindrical support member). The complex nature of the offshore platform as a

noise source is illustrated by Figure 4 which diagrams some of the possible noise sources and paths by which their noise energy may propagate.

(2) Support Vessels. Work boats and supply boats are very important to offshore petroleum operations, and are very often tied up to platforms, or are moored or are maneuvering in the immediate vicinity. These boats are generally twin screw, gasoline or diesel powered vessels of length from 60 to over 300 feet. During transit and maneuvering operations their cavitating propellers produce high levels of broadband noise, covering a wide frequency range from infrasonic frequencies of the order of 10 hertz to ultrasonic frequencies well above 50 kilohertz. Machinery noise generated by the main engines and auxiliary machinery is also radiated. This is mainly at lower frequencies (less than 5 kilohertz), and does not ordinarily reach as high levels as does propeller cavitation noise. Noise radiated from such surface vessels is well documented in the literature (Urick, 1975; Ross, 1976; Leggat, 1981). Although recordings of noise from work boats were obtained in this study, they have not been analyzed.

(3) Helicopters. Nearly all offshore rigs are equipped with helicopter landing platforms, and helicopters often are a major means of personnel and equipment supply. Helicopters are substantial sources of noise, and even though much of the sound energy impinging on the water is reflected, a significant amount of sound penetrates into the water under the helicopter, and is propagated as underwater sound. The sound entering the water is principally that contained in a cone directed vertically downward having a half-angle of 13 degrees as shown in Figure 5. Data on underwater noise associated with helicopter hover and flyover are available in the literature (Urick, 1972; Young, 1973). In general, the noise depends on the helicopter type, flight conditions and altitude, depth of measurement point, and distance from point immediately beneath the aircraft. Secondary factors affecting the helicopter noise level in the water are the surface roughness, ocean

sound-speed profile, and absorption characteristics of the sea bottom. For a given helicopter, whose noise spectrum in air at a given distance below the aircraft is known, the underwater sound field characteristics may be calculated when the above parameters are given. The geometric concepts and mathematical expressions for such calculations are presented (Urick, 1972 and Young, 1973). Because of the general availability of helicopter noise data, no recordings or measurements of helicopter noise were made in the studies reported here.

(4) Seismic Exploration Sounds. These sounds are generated to penetrate the sea bottom and its underlying geological structure in such manner that reflections and refractions from various layers and structural discontinuities may be received and recorded for analysis of the subterranean formations to assess the probability of trapped oil and gas. This requires that sound pulses of very high peak pressure, with major energy content in the low-frequency region (5-500 Hz) be generated in the water. Maximum source levels have been estimated at 230 to 270 dB relative to 1 micropascal at a distance of one meter for the Vibroseis, Air Gun, and explosive sources used for seismic exploration (Acoustical Society of America, 1980). These are almost certainly the highest sound pressure levels associated wih offshore oil and gas operations. The pulses are of short duration (generally less than one second) and are generated intermittently for relatively short periods (of the order of a few months) in any given area.

(b) Acoustic Characteristics of Offshore Oil and Gas Related Noise. A description of the noise associated with OCS oil and gas operations must consider those properties of the noise which are readily relatable to the characteristics of the source which generates them, and also the receivers whose response to the noise is of prime concern. In this case the receivers are the marine animals which might be impacted by the noise. The acoustic characteristics of interest are:

(1) Sound Pressure Level. This is the measure of magnitude of the sound. For underwater sound it is usually specified in terms of decibels relative to a reference sound pressure of 1 micropascal. It is very important to specify the distance from the source, as the sound pressure level is highly dependent on distance. Convenient distances for measurement of sound pressure level are often of the order of 50 to 500 feet.

(2) Source Level. Source level is often used to compare the level of various sound sources at a standard reference distance. This standard distance has been arbitrarily selected as one meter, or one yard. Since the difference between the one meter and one yard reference distance affects source level less than one decibel, it is usually not critical which reference is used. Source level is determined from a measured sound pressure level at a known distance by calculating what the level would be at a distance of one meter from the source if a certain propagation law were operating. Usually inverse square law is used which assumes that the sound radiates from the source as a spherical wave. This is known as spherical divergence, and the sound pressure decreases 6 dB per doubling of distance from the source. In cases where the actual propagation law applicable to the location of measurement is knowr it may be used for calculating the source level.

(3) Bandwidth. Both the sound pressure level and the source level may be expressed for the radiated sound of the source over the entire range of frequencies (overall level), or for a particular band of frequencies (band level). If a band level is given, both the center frequency and bandwidth must be specified.

(4) Sound spectrum. By determining the band levels in a large number of contiguous bands, data are obtained as to the distribution of sound level vs. frequency. This provides sound spectrum information, which is usually expressed as a spectrum plot in which band level in decibels is plotted against frequency. A standard method for expressing spectrum

information is in terms of spectrum level. This converts the band-level data to a bandwidth of one hertz. Procedures for making such bandwidth conversions are described in Harris, 1979. The spectrum information is very important, for by observing the frequency of major components of the sound one is able to determine what type of machine or process is likely to be the source. The frequency information also makes it possible to identify those animals which have acute hearing sensitivity at the frequencies present in the noise, so may be likely to be affected. A spectrum is generally made up of two types of component sounds: a continuous or broadband spectrum, and spectral lines.

(5) Continuous Spectrum. A continuous or broadband spectrum is a spectrum in which the energy is distributed rather uniformly among the various frequencies. This type of spectrum is generated by random - or nearly random - processes such as breaking waves, raindrops, propeller cavitation, etc. Because it contains a wide range of frequencies it has virtually no tonal or musical character.

(6) Line Spectrum. A second type of spectrum component is the spectrum line. In this case the sound energy is concentrated at one frequency, and shows up as a sharp vertical spike on the spectrum plot at a single frequency. Such a line is generated by a very stable cyclic process, such as a rotating machine at constant RPM. Often machinery such as motors, engines, pumps, etc. generates sequences of lines. Sometimes these lines are integral multiples of a basic frequency which is called the "fundamental" frequency. The integral multiples are termed "harmonics". For example, a motor at 3600 RPM might generate a fundamental component at 60 Hz, with additional lines at the second harmonic (120 Hz), third harmonic (180 Hz), etc. Such harmonic sets are useful clues to the diagnosis of noise sources in cases where the rotation rates of potential sources are known. For additional information on properties of machinery noise and their spectra see Harris, 1979.

(7) Impulsive sound. Impulsive sound is a pressure pulse or series of several pulses of short duration, generally less than one second, and often of the order of 0.1 to 0.001 second. Such sounds generally have a broad spectrum, with major energy content at frequencies corresponding to the reciprocal of the pulse duration; thus, a pulse of 0.01 seconds duration would tend to have its energy concentrated in the vicinity of 100 Hz. In general the spectrum width depends on the shape of the pulse. Pulses with a steep wave front (short rise time) have energy extending to the high frequency region of the spectrum. Major sources of impulsive sound are the seismic exploration operations. Other industrial operations generating impulsive sounds are pile driving, hammering, knocking machinery, etc. Impulsive sounds are also generated naturally by such processes as ice impact and cracking, and by marine animals. Porpoises emit clicks of very short duration for echolocation. Sperm whales emit click-like sounds of longer duration. Various fish, and some crustaceans, such as snapping shrimp also emit impulsive sounds. Where a very large number of such emitters are sounding simultaneously, the net effect is a random series of pressure pulses, producing a relatively steady continuous spectrum. Such is the case near a large bed of snapping shrimp, where the sound is like bacon frying in a pan, and the resulting continuous spectrum may have significant energy up to and above 50 KHz.

3. Summary of Underwater Noise at Eighteen Platforms. The noise characteristics, with particular emphasis on the spectra, of each of the eighteen OCS sites recorded in the field study program are described in Appendices D, E, and F. Table II summarizes the data, and includes a noise rating system designed to rate the platforms as noisy, moderate, or quiet. The system is described in detail later in the section. Briefly, it rates the noise spectrum content in each of three frequency regions relative to certain standard levels of ambient sea noise normally expected to be present in the absence of the platform. It was hoped that such a rating system would yield information which might be related readily to physical characteristics of the platforms,

and so lead to some general conclusions relating noise to the platform construction, power plant, and operating mode. A few tentative observations have been drawn; but, perhaps due to the small data base, no conclusive relations are yet apparent.

In general the noise at the sites studied is characterized by a broadband spectrum combined with a number of spectral lines. Figure 6 shows the spectra for the three Alaska platforms. Figure 7 shows spectra for the Middle Atlantic platform and the two platforms rated noisiest in the Santa Barbara area. Figure 8 shows spectra of the three platforms rated quietest. These are from the Santa Barbara area. The spectra are plotted as spectrum level vs. frequency, with the continuous spectrum shown as a dashed curve, and the spectral lines as vertical lines with a dot at the top to mark the sound pressure level of the line. These spectrum plots are overlayed on standard ambient sea noise curves (Urick, 1975) to show the relationship of the measured noise to expected normal ambient sea noise.

All eighteen platforms measured showed components above the normal ambient sea noise, particularly for line spectrum components, which in some cases exceeded the sea state 6 curve by 45 dB (Figure 7). The maximum line components were generally at low frequencies, in many cases in the 4 to 8 Hz region. These occurred for platforms engaged in drilling or production, with no obvious relationship to one or the other. These components are possibly generated by a rotating machine of 240 to 480 rpm. No specific identification of such individual sources has been made. Platform SSD-1 (Figure 6) shows a prominent line component at 72 Hz which appears to be radiated by the diesel engine exhaust system, whose unmuffled exhaust stacks are directed down at the ocean surface. This same frequency component is very audible in the airborne noise of the exhaust.

The three sites ranked as quiet (Figure 8) are all supplied with electric power via cable from shore. One, FDP-1, also has diesel

power, but has a very effective exhaust muffler. This platform was engaged in both production and drilling. The other two were producing only. In general, none of the measured noise could be directly related to the mechanical action of the drill bits. It is possible that such noise may be generated, but if so there were no readily apparent clues to its identity.

The site ranked quietest was the man-made island (MMI-1) engaged in production only. Its low noise probably results from a combination of several factors: (1) primary power supplied by cable from a remote generator ashore, (2) the inhomogeneous rock and fill composition of the island is probably a poor conductor of sound to the water, and (3) the shallow water at the site mitigates efficient coupling of low-frequency energy into the water.

The rating system used for rating the relative noisiness of the platforms in Table II is an arbitrary system based on the number of decibels by which the noise exceeds that of the maximum standard deep sea ambient curves shown in figures 6, 7, and 8 in three separate frequency regions. The frequency regions are: low frequency (less than 30 Hz), medium frequency (30 to 300 Hz), and high frequency (above 300 Hz). In each band the level of the highest component above spectrum level of the top ambient noise curves (heavy shipping and sea state 6) is determined and tabulated (Table II). After each noise excess, a letter L or B is appended to indicate line or broad band component respectively. Then, a rating of N, M, or Q (Noisy, Moderate, or Quiet) is assigned in each band depending on whether the excess in the band is over 40 dB (N), between 30 and 40 (M), or less than 30 (Q). The combination of the three band excess ratings is then used to get the single composite rating in the right hand column of Table II. It is of interest to note that of the 18 platforms rated, 2 are rated noisy, 13 moderate, 2 quiet, and one, the man-made island, is rated very quiet.

D. Predicted Ranges of Influence of Noise of OCS Platforms.

1. Factors affecting audibility of underwater noise. The prediction of the range of expected influence (maximum distance at which a given response may be expected) for a particular noise is extremely difficult because of the large number of factors involved, many of which are not known with much certainty. Since the objectives of this project require such estimates to provide guidance for planning OCS development in a manner which safeguards the marine environment, predictions are presented in this section, even though they must be very rough approximations, embodying many assumptions not yet verified.

Two approaches are possible to make such predictions. (1) If a body of data were available giving observed responses of each species of animal to measured noise levels from each type of noise from each type of platform, it would be reasonably straightforward to employ underwater sound propagation calculations to determine the distance at which the sound level will occur which produces a given response. Unfortunately, such a body of data is not available, although some progress is being made in this direction. The interview portion of this program, and the aerial observation of whale behavior in Arctic areas are two efforts providing this type of data. (2) A second approach (used in this report) is to apply the source-path-receiver model as suggested (Acoustical Society of America, 1980) to calculate the maximum distance at which a given underwater sound may be expected to be audible by a given animal. This approach employs the passive sonar equation (Urick, 1975) to make such calculations. The procedure for this is rather thoroughly treated in Appendix G, in which maximum auditory detection ranges are calculated for a hypothetical mysticete whale hearing the sound from each of three representative platforms (SSD-1, FP-1, and FP-2) under various assumptions of ambient sea background noise at the location of the listening animal, and various underwater acoustic propagation conditions. The results of these calculations are given in detail in Appendix VII. They are summarized briefly in this section,

following a discussion of the source-path receiver model, and the separate source, path, and receiver data which are inserted quantitatively into the model for the calculation of the detection distances.

2. Source-Path-Receiver Model. The source-path-receiver (SPR) model has proved very useful for the estimation of the range to which a sound may be detected. Its greatest use has been in estimating detection of underwater sounds, and accordingly, the analytic expression for calculating detection range, given the proper quantitative data on source, path, and receiver, is called the sonar equation (Urick, 1975). It was developed for naval applications during World War II and is expressed in two forms: (a) active sonar involving detection of an echo reflected from an object in the ocean, and (b) passive sonar involving detection of sound emitted by a source. The passive sonar model is the one used exclusively in this report.

The elements of the SPR model as used in this report may be described as follows:

(a) Source. The sound source is OCS oil- and gas-related, such as an oil drilling rig, or production platform.

(b) Path. The sound propagation path is a one-way water path between source and receiver. Such paths are generally quite complex, involving vertical curvature of the sound rays due to sound velocity gradients in the water, and multiple reflections from the surface and bottom. In order to carry out the calculations of transmission loss in a reasonably tractable manner, a number of simplifying assumptions relating to the path and its boundaries are made. These have been validated by many years of use in naval applications related to detection of submarine and ship noises by passive sonar (Urick, 1975). The literature contains a large body of both theoretical and experimental data on underwater sound propagation (Urick, 1975). The

sound propagation assumptions used in this report are described in Appendix VII.

(c) Receiver. The receiver in the OCS model is the animal whose behavior is possibly subject to modification by hearing the sound. In order to estimate the greatest range at which a sound may be detected by the animal, it is necessary to determine the weakest sound which is detectable. This is called the "threshold of hearing", and is generally dependent on the frequency of the sound. If the animal is listening in an environment free of interfering noise, the threshold is termed the "absolute threshold". Ordinarily, however, the animal is in an environment in which certain normal sounds of the sea are present. These are caused by wind and waves at the sea surface, by breakers on shore, by distant ships, by natural seismic activity, by ice activity in frigid areas, and by various soniferous marine life, such as snapping shrimp, croakers, etc. The total sum of these is termed "ambient sea noise", and is generally at such a level that the audibility of a sound, such as that of a drilling platform, is limited by interference or "masking" by this ambient sea noise (Myberg, 1978). Therefore, in order to predict the audibility of a sound, one needs to know the "masked threshold" for the animal under the environmental sea conditions at the time. This masked threshold for a given animal is dependent on (1) the noise discrimination capability of the animal (aural critical ratio, or critical bandwidth), (2) frequency component to be detected, and (3) background noise spectrum, which in turn depends on sea state, amount of shipping in the general area, local noise-making animals, etc. The various assumptions in this report relating to these are discussed in Appendix G.

It should be noted that frequency of the sound is a critical factor in each of the elements of the sonar equation: source, propagation, and receiver. Therefore, each of these will be considered as a function of frequency. The source is described by its frequency spectrum at a known distance; sound transmission loss over the sound path is

considered as a frequency-dependent quantity; and receiver minimum-detectable signal is approached in terms of a frequency-dependent threshold based on the ambient noise spectrum.

3. Maximum Ranges of Audibility of Platform Noise. This section will present the results of calculations employing the SPR model to estimate the maximum distance at which various classes of marine mammals may hear the sounds radiated by typical platforms. For this purpose three Alaska platforms have been selected as representative moderately noisy platforms. They are identified as platforms SSD-1, FP-1, and FP-2 in Table I, which gives certain construction and operating characteristics of each. In the SPR model, a source is specified, for which the source noise characteristics are known from actual measurements. In addition, one must specify the sound propagation conditions, and the receiver conditions which control the minimum audible signal. The minimum audible signal is determined by the hearing threshold of the listening animal. This may be determined by the basic sensitivity of the animal's hearing mechanism (absolute threshold); or in the case where the ambient sea noise is audible to the animal the sea noise causes masking, and thereby sets the minimum audible signal. The threshold so determined is called the masked threshold. Signal detection at frequencies in the region of greatest sensitivity (lowest absolute threshold) is almost always limited by the ambient background noise (masked threshold). This is discussed in Appendix G, which includes a fairly detailed treatment of ambient sea noise and animal masked thresholds, and the assumptions appropriate to the selection of quantitative values for insertion into the model. It should be noted that the detection ranges are very dependent on the choice of these parameters and on the sound propagation conditions. Table II summarizes platform noise ratings.

Detection of Platform noise by Mysticete Whales. This section will summarize briefly the calculated detection ranges for the noise of platforms SSD-1, FP-1, and FP-2 as heard by a hypothetical mysticete

whale under various conditions of ambient background noise and acoustic propagation. See Appendix G for detailed discussion. Assumed conditions are described below.

Sound Propagation - Two Cases.

Case I: Optimal Sound Propagation (Cylindrical Spreading)

- Sound pressure level falls off with distance at rate of 3 dB per distance double.

Case II: Conservative Sound Propagation (Spherical Spreading)

- Sound pressure level falls off with distance at rate of 6 dB per distance double.

In each case the total propogation loss consists of the spreading loss plus a frequency dependent attenuation loss described in Appendix G.

Listening Animal: Generalized mysticete whale, such as blue, bowhead, fin, gray, humpback, right, etc. Animal Hearing Assumption - Two Cases: Case A - Good Detection (1/3 octave critical band), Case B - Conservative Detection (100 Hz critical band below 450 Hz, 1/3 octave band above 450 Hz).

Ambient Noise - Three Conditions.

Condition 1 - High Noise:

- Sea State 6, heavy shipping;

Condition 2 - Moderate Noise:

- Sea State 2, moderate shipping;

Condition 3 - Low Noise:

- Sea State 0, light shipping.

Tables III, IV, and V present the predicted most detectable frequency component, and detection range for the three platforms for the various sets of assumptions, outlined above. Note that the frequency components are fairly low (20 to 180 Hz), and the detection ranges vary widely, being highly dependent on the conditions assumed. They vary from a maximum of 2960 nautical miles for platform FP-2, optimal propagation, low ambient, and good detection; to a minimum of 40 yards for less noisy platform FP-1, conservative propagation, high ambient, and conservative detection. Of all the factors, the greatest influence on detection range comes from the sound propagation and ambient noise. For example, Table III, Case IA3, shows the semi-submersible drilling platform to be audible under low ambient noise conditions out to 1230 nautical miles with cylindrical spreading propagation but only to 1.2 miles with the more conservative spherical spreading (Case IIA3).

The ambient noise condition at the location of the receiving animal also has a strong influence on detection as may be observed from Table III. Case IA1 (optimal propagation) shows that for high ambient noise the detection range is reduced to 15 nautical miles, as compared to 1230 miles in low ambient (Case IA3). Case IIA1 (conservative propagation) shows a range of only 190 yards under high ambient noise, compared to 2400 yards (1.2 nautical miles) for low ambient noise conditions (Case IIA3).

It is important to note that the above estimates are intended to provide initial guidelines of maximum and minimum ranges as upper and lower limiting conditions for general planning. The upper limit, Case IA3, is an extreme situation, highly unlikely to be met in practice. Reflection losses at the surface and bottom result in propagation which will in general fall between Case I and Case II, probably more often

nearer the spherical spreading of Case II. For example, a published estimate of propagation loss out to 50 nautical miles (101 kiloyards) for the continental shelf off the northern coast of Alaska is 80 to 120 dB for a frequency of 100 hertz (Underwater Systems Inc., 1974). This is much greater than the 50 dB shown for cylindrical spreading in Appendix G, Figure 3, and, in fact, brackets the 100 dB shown for spherical spreading.

A second factor which makes unlikely the extreme ranges calculated for low ambient noise is the upward trend in ship noise during the last few decades (Ross, 1976). At low frequencies the present levels of shipping make it highly unlikely the light shipping noise in Appendix G, Figure 4, will be experienced, except in very remote locations. The moderate curve serves as a much more probable lower limit to low frequency ambient noise.

The above considerations suggest that a realistic interpretation of maximum expected ranges in Tables III, IV, and V would best disregard the possibility of the extreme ranges associated with Case I (cylindrical spreading) and ambient noise condition 3 (low). This suggests that the more probable limiting ranges would fall between Case IIA2 and Case IA2. This would place the expected maximum detection range between 0.22 and 99 nautical miles for platform SSD-1 (Table III); between 0.17 and 59 nautical miles for platform FP-1 (Table IV), and between 0.49 and 490 nautical miles for platform FP-2 (Table V).

Recognizing that the calculated data presented in Tables III, IV, and V are intended to demonstrate the wide spread of possible ranges, and their dependence on the various controlling factors, a separate set of calculations have been made to present most probable ranges expected for three specific OCS areas. These are presented in Section D-4.

<u>Detection Range Estimates for Odontocetes</u>. The detection range estimates above were all for a generalized mysticete whale, having good

low frequency hearing. The remainder of this section will deal with a similar type of calculation, but much restricted in scope, for odontocetes (the toothed whales) which include dolphins, porpoises, and some whales such as the orca (killer whale) and sperm whale.

Acoustically, the odontocetes differ from the mysticetes in two general ways: (1) they echo-locate, and (2) their acoustic system for echolocation and communication operates at higher frequencies (generally from 1 to over 100 kHz). Table VI summarizes acoustic characteristics of some odontocetes. Because they operate at higher frequencies, resulting in shorter wave lengths, the acoustic receiving and transmitting systems of these animals tend to be directional and are capable of discriminating against unwanted noise. This adds one more factor to be included in calculations of acoustic detection range - the capability to discriminate against a masking noise background by virtue of a directional hearing system. The quantitative measure of this capability is the directivity index (DI) in decibels. The directivity index is zero for cases where no directional discrimination against noise is realized. This was assumed for the mysticete whales. The directivity index depends in general on the ratio of the size of the animal's receiving system to the sound wavelength. This ratio can become quite large for animals listening at frequencies in the 10 to 100 kHz region where wavelengths lie between 6 and 0.6 inches.

For calculation of detection range by an odontocete, the beluga whale is selected, since its threshold of hearing has been measured (White et al., 1978). Figure 9 shows the absolute hearing thresholds for two odontocetes which have been measured experimentally by behavioral techniques, these are the beluga whale and bottlenose dolphin. Both show excellent hearing at frequencies above 5 kHz out to, and beyond, 100 kHz. This matches the frequency region of their echolocation pulses which is shown in a summary table (Herman, 1980) to be 25 to 200 kHz for the beluga whale and 0.2 to 150 kHz for the bottlenose dolphin.

As pointed out in the earlier section dealing with the "receiver" element of the SPR model, the weakest sound detectable by an animal, sometimes called the minimum detectable signal (MDS) is determined by the absolute threshold, or the masked threshold, whichever is greater. Figure 10 shows both the absolute thresholds and masked thresholds for the beluga whale, bottlenose dolphin, and harbor seal. The masked threshold assumes a one-third octave critical band for all three animals, and a masking background of moderate shipping noise (below 200 Hz) and ambient sea noise for a sea state 2, which corresponds to a reasonably prevalent, moderate wind and wave condition. The sea state curve dominates the shipping noise at frequencies above about 200 Hz. The MDS level is determined from Figure 10 by observing, for a given animal, the higher of the two curves: the absolute, or masked threshold. For example, in the case of the beluga whale, the absolute threshold controls the MDS at frequencies below 4 kHz, above which the masked threshold controls. It should be pointed out that the masked threshold curve for the ambient sea noise shown in Figure 10 is simply the third octave band spectrum of ambient noise for sea state 2. It does not include any advantage which may accrue by the suppression of background noise by the directivity index (DI) of the animal's listening system. Very little is known about the DI for marine mammals, but it would appear appropriate to include a DI correction where the physical dimension of the animals hearing system is comparable to the wavelength. The calculation of detection ranges for the beluga whale, summarized in Table VII, assumes a DI of 5 dB at a frequency of 5 kHz.

The maximum hearing sensitivity for the beluga as shown by its lowest absolute thresholds in Figure 10 falls between 20 and 70 kHz. At these frequencies the beluga's hearing is likely to be limited by masking by the ambient sea noise. Note that the Sea State 2 one-third octave band curve in Figure 8 is about 30 dB above the absolute threshold at frequencies between 20 and 70 kHz. This suggests that detection will be limited by masking noise, unless the animal's directional discrimination against the ambient noise, as characterized by the DI is

sufficient to reduce the noise heard by the animal by 30 dB. This is not likely, at least for frequencies below about 50 kHz, at which frequency the wave length is sufficiently short that the shielding properties of the beluga head could produce a DI of the order of 30 dB. The DI of 5 dB assumed for the beluga at 5 kHz is just sufficient to bring the masked threshold down to about one decibel below the absolute threshold, so the calculations of minimum detectable signal (MDS) shown in Table VII, are based on the absolute threshold of 74 dB shown in column 5 for the three platforms. Combining this with the appropriate one-third octave band source levels shown in column 3, signal excess, in dB available for propagation. This is 28, 43, and 29 dB respectively for the three platforms. These may be converted to expected detection range by use of the acoustic propagation curves of Appendix G, Figure 3. This results in the ranges shown in the last two columns of Table VII. In general, these ranges are quite short (less than 800 yards), even under best propagation conditions, except for platform FP-1 which has a much higher source level at 5 kHz than the other platforms. This appears to be due to a strong spectrum line at 5 kHz, perhaps generated by its gas turbine. This platform shows a detection range of 5 nautical miles under optimal propagation conditions, but only 150 yards under conservative (inverse square) propagation conditions. In general, these ranges are much shorter than those calculated for the mysticete whales, which are assumed to listen at lower frequencies.

Detection Range Estimates for Pinnipeds. The same methodology as used above for mysticetes and odontocetes is here applied to pinnipeds, such as seals and sea lions. Data on absolute underwater hearing thresholds for four species of pinnipeds are shown in Figure 9 of Appendix A. In general, the underwater hearing for all species is fairly similar, becoming more sensitive toward the high frequencies, with maximum sensitivity in the 10 to 50 kilohertz region. Their hearing in the region of greatest sensitivity fails to match that of the odontocetes by a significant amount. Figure 10 plots the absolute hearing threshold

versus frequency for the harbor seal (Phoca vitulina), together with those of the beluga whale and bottlenose dolphin. Note that both the latter show significantly better hearing (lower thresholds) than the harbor seal at high frequencies. At lower frequencies below about 7 kHz the harbor seal appears to hear better than the beluga whale, and at 1 kHz has a threshold which matches that of the bottlenose dolphin (Figure 10). The harbor seal was selected for the pinniped calculations because it appeared to have the best hearing of the four species shown in Appendix A, Figure 9. At the calculation frequency of 5 kHz the absolute threshold of the harbor seal is about 5 dB more sensitive than that of the beluga whale, as seen in Figure 10. It is also about 8 dB below the 1/3 octave band masked threshold curve for ambient noise of sea state 2 also shown in Figure 10. This means that the masked threshold will control detectability. The masked threshold value of 78 dB at 5 kHz will not require any adjustment for directivity, as the DI for the harbor seal is assumed to be zero. This is based on the small size of the seal's head compared to the wavelength of the sound.

To enable ready comparison of detection ranges for the harbor seal and beluga whale, Table VII lists for both animals the detection ranges for sounds radiated from the same three platforms. The slightly higher (less sensitive) threshold for the harbor seal results in slightly shorter detection ranges, as shown in the two right hand columns of the table. As mentioned previously for the beluga whale, the ranges are generally quite short, falling between 15 and 300 yards for platforms SSD-1 and FP-2, and increasing only to 3 nautical miles (6 kyd) for the noisiest platform (FP-1) and optimal propagation. For the more likely inverse square propagation the range for hearing FP-1 is only 90 yards.

4. Typical Ranges of Audibility for Three Specific Areas. The previous section showed that ranges of audibility by marine animals of sounds of oil platforms may range from a theoretical high of over 2000 miles to a low of 15 yards, depending on the many factors affecting

sound detection and propagation. This section selects three specific sites, and calculates the expected detection ranges for representative animals under typical oceanographic conditions in the respective areas. The three sites selected are: (1) Alaska: lower Cook Inlet; (2) California: Santa Barbara-Point Conception area; and (3) Middle Atlantic: Baltimore Canyon area. The conditions assumed for the detection calculations are summarized in Table VIII. The platform selected is SSD-1, a semi-submersible drilling unit which was measured during drilling operations in lower Cook Inlet, Alaska, and which is a sister ship to SSD-2 which was measured in the Middle Atlantic area. Animals selected as typical to each area are: (1) lower Cook Inlet, Alaska: gray and beluga whales, harbor seal (Bureau of Land Management, 1980) (2) Santa Barbara, California: gray whale; and (3) Middle Atlantic: fin whale (Leatherwood et al., 1976). For these calculations, the fin and gray whales are considered to be typical mysticete whales, so their detection thresholds are masked thresholds as described in the previous section dealing with mysticete whales. Results are shown in Tables III, IV and V, listening assumption A (Good Detection), which assumes 1/3 octave critical bands at all frequencies between 20 and 5000 hertz. The ambient noise and sound propagation conditions are selected as appropriate to the area: (1) lower Cook Inlet: sea state 3, moderate shipping, good propagation (cylindrical spreading), Spring, Summer and Fall; (2) Santa Barbara, California: sea state 3, heavy shipping, conservative propagation (spherical spreading), Fall, Winter, Spring; and (3) Middle Atlantic: sea state 4, heavy shipping, conservative propagation (spherical spreading), all year. The above estimates of sea state are based on average wind speed and wave height data (U.S. Navy, 1974 and 1977) and shipping density is estimated from proximity to major shipping ports and lanes (see Bureau of Land Management, 1980, and Wales et al, 1981).

The calculated detection ranges for the noise of platform SSD-1 are shown in the right column of Table VIII. The 250 yard range for the beluga whale in Alaska is substantially less than the 10,000 yard range

shown in Table VII for the Beluga listening to platform FP-1. This is because platform SSD-1 has a source level at 5 KHz 15 dB less than that of FP-1. The relatively short range of 150 yards for the gray and fin whales off California and in the Middle Atlantic area is a result of relatively high masking by the high background noise due to high shipping densities in those areas, together with assumed conservative propagation with spherical spreading, based on typical sound velocity gradients. If optimal propagation (cylindrical spreading) were assumed, the range for each would increase to 22,000 yards (11 nautical miles). It is likely that propagation will fall somewhere between spherical and cylindrical spreading, but more likely nearer spherical, giving the shorter ranges. If propagation intermediate between spherical and cylindrical spreading (4.5 dB/dd) is assumed, the detection range is 900 yards (Table VIII). Propagation estimates are based on oceanographic features of each area, principally vertical gradients of underwater sound velocity (National Oceanographic Data Center, 1968), which govern the upward and downward refraction (bending) of the sound propagation paths, and water depth. The assumption of good propagation (cylindrical spreading) in the lower Cook Inlet area is largely based on our measured data on the sound of platform SSD-1, which showed approximately a 3 dB per distance double relationship at measurement distances between 50 and 800 feet from the platform. The water depth here was approximately 200 feet. The calculated detection range of 100 miles for the gray whale in the Cook Inlet, Alaska area, is probably unrealistically high for several reasons related to the propagation assumptions. (1) It was assumed that the propagation path was free of obstacles which might produce acoustic shadows. There are many land masses, such as islands in this area which would strongly influence propagation. (2) The assumed cylindrical spreading (3 dB per distance double), though actually observed in the specific locality of platform SSD-1, is probably not typical of the entire lower Cook Inlet area. For example, one publication (Underwater Systems Inc., 1974) estimates the propagation loss for a range of 50 nautical miles over the continental shelf of the northern coast of Alaska to be 80 to 120

dB for a frequency of 100 Hz. This is much closer to the 100 dB expected from spherical spreading than to the 50 dB expected for cylindrical spreading assumed in Table VIII for lower Cook Inlet. A spreading rule half way between the 3 and 6 dB per distance double relations might be a suitable compromise. Using this (4.5 dB/dd) rule the detection range for the lower Cook Inlet gray and fin whales is 3500 yards, or 1.8 nautical miles (Table VIII).

E. Predicted Effects of Noise on Marine Mammals.

The previous sections show that the marine mammals may be expected to hear the sounds of offshore oil and gas operations out to distances as far as 100 nautical miles, and even farther under highly favorable conditions of sound propagation and ambient noise. This section addresses the core problem--what effects might these sounds produce on the animals exposed to them?

The effects of noise on wildlife have been the subject of several recent meetings, and have led to at least two publications relevant to this report. At a symposium on the Effects of Noise on Wildlife held at the 9th International Congress on Acoustics in Madrid in 1977 existing knowledge of the effects of underwater noise on marine animals was summarized (Myrberg, 1978). In February 1980 a workshop was sponsored by the Acoustical Society of America on The Interaction Between Man-Made Noise and Vibration and Arctic Marine Wildlife (Acoustical Society of America, 1980). Concern over possible effects on marine animals of the underwater noise from the LNG tanker proposed in the Canadian Arctic Pilot Project resulted in the holding of an Underwater Noise Workshop in Toronto in February 1981. The proceedings of this workshop have been published (Arctic Pilot Project, 1981) and copies of various papers presented at the workshop are available (Terhune, 1981; Ross, 1981; and Leggat 1981) These relate to many aspects of possible noise effects.

Although little data are available on directly observed effects of noise on marine mammals, it is possible to make fairly reasonable speculations based on the above references and analogies between marine mammals and man, about whom considerable knowledge of the effects of noise exists (Kryter, 1970; Harris, 1979). This animal-man analog is somewhat deficient in the case of cetaceans, since their hearing mechanism has evolved to match the undersea environment, and therefore differs from that of terrestrial animals, such as man, in many ways. For example, the marked difference in the external and middle ear system between cetaceans and terrestrial animals, such as man, may be expected to result in some differences in auditory action which could cause cetaceans to differ from man in such responses as adaptation to loud sounds, noise induced hearing loss, pain threshold, etc. In view of these differences, an attempt is made to point out the weaknesses of human response analogies where they are used.

Sounds of very high sound pressure level produce in man several effects, some of which are related to high levels of excitation of the auditory nerve system, and therefore are associated with extreme loudness sensations; and others are related to an excessive mechanical-vibratory stimulation of tissue, with consequent stimulation of non-auditory sensory systems, such as pain, feeling, orientation, thermal, etc. So little is known of the latter (non-auditory) types of responses in cetaceans, that no definitive discussion is possible at this point. It would seem unlikely, however, to expect adverse responses to even very high pressure noise disturbances from animals which are adapted to life in the sea, where pressure changes of the order of many atmospheres in magnitude are routinely experienced in ocean margin earthquakes (Northrop, 1972), or diving; and particularly for the animals, such as cetaceans which normally jump free of the surface and return with a diving splash which creates a sudden large increase in pressure. As a rough estimate this pressure might easily correspond to that of 3 feet of water (approximately 0.1 atmosphere). This corresponds to a peak sound pressure of about 1.5 pounds per

square inch, or approximately 200 decibels above 1 micropascal. No steady state sound pressure levels associated with oil and gas operations come even close to such levels. The only sources which produce such high pressures are impulse sources used for seismic surveys. Source levels for sources normally used in seismic work (non-explosive) are estimated (Acoustical Society of America, 1980) at 230 to 240 dB at 1 meter. Even for these very high pressure sources, the sound pressure level is expected to be under 200 DB at distances beyond 100 yards. It does not appear likely that marine mammals would suffer any of the non-auditory effects from noise of any of the normal oil and gas operations, even including seismic surveys, at distances beyond 100 yards.

Occasionally in seismic survey work explosive sources are used. The source levels for these are very high, and have been estimated (Acoustical Society of America, 1980) at 270 dB at 1 meter. This corresponds to a source pressure 50 dB above, or 300 times atmospheric pressure; such pressures might adversely affect animals. If spherical spreading of sound pressure is assumed, the level would fall to 200 dB at 3,000 yards, beyond which non-auditory effects are unlikely. The effects on animals of a sonic boom, which is a sound pulse somewhat similar to the seismic pulses, have been recently studied in connection with proposed launches of the Space Shuttle over offshore waters near Point Conception, California (Evans et al., 1980; Cooper and Jehl, 1980). These studies concluded that occasional peak overpressures in air of 30 pounds per square foot, which corresponds to about 184 dB re 1 μPa would have no significant physiological effect on the marine mammals of the area, which includes both pinnipeds and cetaceans. Possible auditory effects from high level sounds include startle, flight (rapid escape), hearing loss, and auditory discomfort due to excessive loudness. A possible additional effect is the masking of wanted sounds, such as communication, echo-location, and food-finding signals. As mentioned above, little data are available for such animal

responses, but analogous human responses provide one approach for estimating some effects.

1. Excessive Loudness For humans, sounds tend to become uncomfortably loud at levels of the order of 100 to 120 dB above threshold (Harris, 1979). This would correspond to sound levels of approximately 143 to 180 decibels for the beluga whale, bottlenose dolphin, and harbor seal in the frequency regions of their greatest sensitivity (Fig. 10). Levels measured at the various platforms are generally well below 110 dB at a distance of 50 feet for frequencies in this high sensitivity region, so it is unlikely that platform noise would be uncomfortably loud to these animals at distance beyond 50 feet. It is difficult to extend this argument to mysticete whales, since their absolute hearing thresholds have not been measured; however, we might reason from a rather liberal assumption that their hearing threshold at low frequencies might be as sensitive as is that of the beluga whale at high frequencies. This is 43 dB re 1 μPa as shown in Fig. 10. Adding 100 dB to this gives 143 dB as a level which might conceivably be uncomfortably loud to a mysticete whale. Actual measurements on platforms reported in this study show no levels exceeding 136 dB at distance of 20 feet or beyond, either as measured, or calculated for 20 feet using the spherical spreading rule. This would suggest that all cetaceans may, by remaining at a distance no closer than about 10 or 20 feet from a platform, avoid uncomfortably loud noises from the platform.

2. Noise-Induced Hearing Loss A similar argument to the above may be used to assess the possibility of noise induced hearing loss. To use a human analogy, the most susceptible humans experience a significant hearing loss if they are exposed 8 hours per day for a period of 10 years to a sound about 80 dB above their absolute threshold (Harris, 1979). Note that hearing damage is a cumulative process, requiring a combination of high sound level and extended periods of exposure. The damage process involves a "fatigue" of the

auditory sensory nerves which are able to partially recover during periods of quiet, thus the time sequence of exposure is important. A continuous exposure is generally more serious than an interrupted one which gives intermittent periods of recovery. The previous paragraph showed that beyond 20 feet from the platform the sound pressure levels of the platforms measured in this study would not be expected to exceed 136 dB. This is 13 dB above the level of 123 dB estimated as a possible threshold of hearing damage by adding 80 dB to the most sensitive absolute threshold (43 dB in Fig 10). It may be estimated that for the noisiest platform measured the sound would be reduced to 123 dB at a distance of 100 yards. This assumes cylindrical spreading (3 dB per distance double) for a conservative estimate. Assuming spherical spreading (6 dB/dd) the animal would only need to be 10 yards distant for a level of 123 dB. Thus, either case would seem to assure a readily available zone of quiet which the animal could seek out to avoid a deafening noise. Terhune (1981) states: "It does not seem unlikely that marine mammals would flee from a very loud sound." It should be pointed out again that the general approach above is based on many unverified premises, but it would seem to be useful for an initial attack on a problem area in which direct data are unavailable.

3. Other Physiological Effects. Various other physiological effects of high level noise have been observed in humans (Harris, 1979). These include such things as the startle response, the orienting reflex, and the defense reflex. Other responses observed in humans are changes in heart rate, contraction of blood vessels (vasoconstriction), and effects on body chemistry, particularly with respect to hormone production. Experimental animals such as rats exposed to high level noise exhibit some similar effects, particularly adreno-cortical responses. In general this entire area of physiological effect is so little understood, for man as well as for animals, that speculation of effects on cetaceans does not appear justified. As discussed above, however, noise below the levels of auditory discomfort and hearing damage is unlikely to produce any serious physiological effects.

4. Effects on Communication and Echolocation. The fact that an audible sound is capable of masking (interfering with the audibility of another sound) introduces an area of potential effects especially relevant to cetaceans, which are known to depend highly on acoustically derived information. They use acoustical signals for communication, location of food, and avoidance of possible hazards. Masking, and the concept of the masked threshold was discussed earlier in the section dealing with the range of audibility of oil platform noises in the presence of masking by normal ambient sea noise. It was pointed out that the masked threshold is reached for a given wanted sound (here called a signal) when the level of the signal in a given critical band is equal to the level of the masking background noise in the same critical band. This same principle may be used to estimate the masking effect of oil- and gas-related noises on echolocation and communication.

5. Masking of Animal Echolocation Signals. Terhune (1981) used the above method to predict masking effects of noise from a proposed high-power icebreaking LNG tanker. He concluded that echolocation signals of the bottlenose porpoise and the harbor porpoise, both of which have maximum signal energy at frequencies of the order of 100 kHz, would be masked by the noise of the tanker (100 kHz source level 118 dB re Pa per Hz at 1 yd) when quite near the tanker, but he states that beyond 1 kyd the tanker noise would not cause appreciable masking at the echolocation frequencies. It is important to note that the masking of a signal is mainly dependent on the masking noise energy in the same frequency band as the signal. The LNG tanker in the above example generates high noise in the echolocation frequency region of the two porpoises. The same prediction technique applied to the sounds of oil and gas platforms predicts little significant masking at the echolocation frequencies because the platforms radiate so little noise at those high frequencies, which are also transmitted very poorly in sea water. The platform noise spectra shown in Appendices E, F, and G generally show the spectrum level sloping downward toward high frequencies at a rate of about 5 dB per octave. Extrapolating to high

frequencies from 10 kHz at which the highest measured spectrum level was 75 dB at 100 feet, the spectrum level at 100 kHz is 75-17 dB = 58 dB. This is 33 dB above the spectrum level of ambient sea noise of sea state 2, which has a spectrum level of 25 dB, so at a distance of 100 feet from the platform would be expected to produce masking significantly above that provided by the ambient sea noise. This high frequency platform noise will, however, decrease very rapidly as the distance of the animal from the platform increases, so at a range of about 800 yards and beyond, the masking of echolocation signals will be less than that of sea noise of sea state 2. This is a very conservative estimate, since it is based on the noisiest platform, cylindrical spreading, and does not give the animal the advantage of directional discrimination, which would work to its advantage except for the specific case where the echolocation target was in line with the platform. Myrberg (1978) discusses effects of noise on echolocation by the bottlenosed porpoise, and notes that they increase their source level under noisy conditions. He concludes that "...effects of traffic (or industrial) noise upon sensitivity appear essentially nil."

6. Masking of Animal Communication Signals The masking effect of platform noise on communication signals may be appraised in the same manner as above, by calculating the range at which the platform noise no longer exceeds the normal ambient sea noise. Of course the calculation must be for the frequencies employed by the communicating animal. The characteristics of communication signals for cetaceans are described by Herman and Tavolga (1980). For evaluating possible masking effects, three species with well-known signal properties believed to be used for communication are selected: (1) mysticetes: fin whale (20 Hz) and humpback whale (0.2-5 KHz). (2) odontocetes: killer whale (1-4 kHz) and bottlenose porpoise (2-20 KHz). These signals involve two general regions of frequency: a low frequency of 20 Hz and a high frequency region between 1 and 20 KHz. For the following analysis, two frequencies: 20 Hz and 2 KHz are selected for assessing

masking. The selection of 2 KHz as representative of the 1-20 KHz band is arbitrary, but the exact frequency selected is not critical, as the masking spectra being compared, namely platform noise vs ambient sea noise, appear to be roughly parallel over the 2-20 KHz region. For the fin whale at 20 Hz, a masked threshold was considered earlier as being established by shipping noise expected to be at moderate to high levels at most OCS locations of interest. Moderate shipping noise (Urick, 1972) has a 20 Hz spectrum level of 75 dB, or critical band level of 82 dB. The noisiest platform at this frequency (FP-2) has a strong component at 20 Hz of 132 dB at a distance of 20 feet. This could interfere with the reception of 20 Hz pulses by fin whales near the platform, but if reduced by 50 dB would fall to the level of moderate shipping noise. This would occur at a range of 0.8 kyd for spherical spreading (6 dB/dd), 700 kyds (350 n.m.) for cylindrical spreading (3 dB/dd), or 7.5 kyds (3.75 n.m.) for the intermediate propagation condition hypothesized earlier (4.5 DB/dd).

Communications at frequencies in the vicinity of 2 KHz (humpback and killer whales, and bottlenose porpoise) will now be considered in a manner similar to the above, by calculating the range at which the spectrum level of the platform noise at 2 KHz is reduced to that of the normal ambient sea noise. In this case a normal sea state will be considered to be rather conservative (sea state 2), which is somewhat quieter than the sea states of 3 and 4 noted as average for the three specific OCS sites of Table VIII. The spectrum level at 2 KHz for sea state 2 ambient noise is approximately 53 dB. The noisiest platform at 2 KHz produced a broad band spectrum level of 81 dB at 100 feet. This is 28 dB above that of the ambient noise, but would be down to the ambient noise level at a distance of 0.8 kyd assuming spherical spreading (6 dB/dd), or 6 kyd (3 n.m.) for the intermediate propagation assumption (4.5 db/dd).

The above calculated ranges are the distances at which the sound from the noisiest platform of those measured in this study just equals that

of the ambient sea noise, so at such ranges the platform noise just begins to be capable of slight masking of animal communication signals. This represents the extreme limit of possible masking effect. Normally the animal signal is well above the masked threshold, so considerable masking may be experienced without blanking communications. Where the communication signal consists of several frequencies, or is frequency modulated to cover a band of frequencies as is the case with many cetaceans, it is unlikely that all of the components will be masked by the platform noise. Some communication may be expected, even though it may be somewhat handicapped. A strategy used by humans is to increase the vocal level when in a noisy environment. As noted by Myrberg (1968), it is possible that this may be done by animals, particularly if the noise is audible to the animal producing the signals. Bottlenosed porpoise in noisy Kaneohe Bay, Hawaii, have been reported (Au et al., 1974) to exhibit an adaptive response by increasing both level and frequency of echolocation signals relative to those of the same species in a quiet environment.

The effects of platform noise on animal echolocation and communication may be summarized as follows: The echolocation signals are generally at high frequencies, at which the platforms emit little noise, and propagation is poor due to absorption of sound in the sea. This, coupled with probable directional discrimination of the animals at the high frequencies makes it unlikely that any significant interference with echolocation will occur. Communication, on the other hand, tends to take place at lower frequencies, at which the platforms emit relatively large amounts of noise, underwater sound propagation is good, and animal directivity index is small. Interference with communication is possible in some cases, particularly for whales such as the fin whale which appears to use a single frequency of 20 Hz with very little apparent modulation or variability. Although slight interference may be possible out to a range of 350 miles under extreme conditions, it is much more likely to expect the range of effect to be less than about 4 miles, even for a platform such as FP-2, which had a

strong noise component at 20 Hz. The animals which use frequencies in the 2000 Hz region generally use complex and modulated signals which are likely to be less susceptible to interference. It does not appear that any serious interference with their communication is likely. Even though slight masking might be experienced out to a range of 35 miles from the noisiest platform, a range of 3 miles for "beginning sking" would seem more realistic. The high source levels of the commu ation signals are such that they generally exceed the source level of the platform noise at their communication frequencies; therefore it may be concluded that if the distance between the communicating animals does not exceed their distance to the platform they should experience no appreciable interference. For example, bottlenose porpoises 100 yards apart should be able to communicate with no interference if the porpoise nearest the platform is 100 yards or more from the platform. The high intensity of the communication whistles of the bottlenosed porpoise would suggest that they would experience no significant interference even at distances much less than 100 yards from the platform.

It may be noted that the effect of masking is to shorten the distance at which the signal may be heard. The shortening of distance may be determined as the distance over which the sound propagation loss is equal to the amount of increase in the masked threshold by noise. Thus, if a platform increases the ambient noise by 6 dB, the communication distance for 20 and 2000 Hz sounds will be halved assuming spherical spreading, or reduced to 1/4 assuming cylindrical spreading.

A thorough assessment of the effects of OCS platform noise on the well-being of marine mammals would require detailed calculations of the communication distance in the vicinity of various platforms in specific localities for the species of interest. This could then be interpreted in terms of necessary distances for the normal social interactions of the species, such as feeding, courtship, mating, migration, seeking of the herd, habitat, etc. This is beyond the scope of this report.

F. Observed Behavioral Reactions to Sounds

It has been noted in earlier sections that there are several stages in auditory perception of a sound. These are, in order of increasing intensity: (1) Detection - the first point at which a sound differing from the normal ambient is perceived. Normally, there is insufficient information content at this point for recognition of the sound source, so any marked reaction is unlikely. Orientation of the animal for optimal reception might conceivably occur. (2) Recognition of the sound source. This is called classification in sonar practice, and normally requires that a substantial portion of the sound spectrum be audible. This is likely to require a signal-to-noise ratio of perhaps 10 to 20 decibels. At this point behavior will depend on the significance of the source object to the animal. If it is perceived as a threat, a retreating or flight reaction may occur, or the animal may orient in a direction for future retreat. If it is perceived as a non-threat, no change in observed behavior is likely. (3) Sound becomes excessively loud. For humans, this is called the threshold of discomfort, and occurs at levels 100 to 120 dB above the threshold of audibility. When sounds become this loud the animal may be expected to show retreat or flight behavior in an attempt to reduce the sound level by opening range, or changing depth. (4) Sound intensity becomes so great as to produce physiological effects, such as hearing damage, pain, disorientation, etc. Data are not available on such effects in marine mammals, but one might expect flight reactions similar to condition (3) above, with the possibility of some added erratic behavior in the event of disorientation.

Direct observations of the behavior of marine mammals attributable to acoustic stimuli are very limited, and are difficult to interpret inasmuch as the acoustical stimulus often occurs with visual or other stimuli, which may contribute to the observed behavior. Earlier sections of this report discuss observations of animals from oil and gas platforms, work boats, and helicopters. These are described in

detail in Appendix III. In general no behaviors were reported which appear to represent aversive or flight action, except near helicopters. Recent observations in the Beaufort Sea (Richardson, 1981) from aircraft, boats and shore stations were accompanied by acoustical measurements, and provide perhaps the best available data on the behavior of bowhead whales in the vicinity of noise sources. These are summarized briefly in the following sections.

1. <u>Boats</u> (Richardson, 1981) Boats are reported as the most widespread source of disturbance of bowheads in the Beaufort Sea. A 53-foot crewboat with twin diesel engines was reported to cause whales at a distance of 3.7 kilometers to respond to the start up of its engines by reducing the time at the surface and tending to orient facing away from the boat, even though it produced no propeller noise as its propellers were not engaged. Sound measurements with a sonobuoy near the whales indicated that the boat sounds exceeded the ambient noise by about 25 dB at most frequencies between 500 and 2000 Hz. When the same boat (underway) approached the whales fairly closely such that sounds were about 40 dB above the ambient at frequencies below 500 Hz, and about 10-40 dB at 500 to 4000 Hz, marked behavioral reactions were observed (whales moved away rapidly). The whales returned later after the boat left the area.

2. <u>Aircraft</u> (Richardson, 1981) Bowheads in the Beaufort Sea reacted by diving when circled by an Islander or Twin Otter aircraft at 1000 ft altitude. They did not appear disturbed by overflight at 1500 ft or more. This behavior may be variable, for in the eastern Canadian Arctic area, Bowheads overflown by a Twin Otter at 500 ft altitude did not usually dive on the first pass, but when overflown at 300 ft nearly always dove. It appears likely that the bowheads are more sensitive to aircraft than are other baleen whales, since various observers report very little disturbance of right, humpback, sei, fin and southern right whales during overflights above about 300 feet.

3. <u>Artificial Island Construction</u> (Richardson, 1981) Many bowheads were observed within 5 km, and as near as 0.8 km to an artificial island under construction which involved dredges, tugs, a barge camp, etc. The sounds from this operation were well above ambient noise, and were measured at 4.6 km from the dredge to be 10 to 20 dB higher than sounds of the idling engines of the 53 foot boat to which bowhead responses were observed. It is stated that the presence of construction operations at this location (in the Canadian Beaufort) in the summers of 1978-1980 has to date produced no discernible decline in utilization of the area by bowhead whales.

4. <u>Seismic Exploration</u> (Richardson, 1981) Observations of a group of 7 bowheads within 13 km of a seismic exploration vessel showed no obvious disturbance of behavior. Surface times, intervals between blows, and blows per surfacing were normal. The sound level at the animal location was stated, to be at least 135 dB re 1 μPa, and possibly as high as 146 dB. Ljungblad (personal communication) reports observing normal behavior of gray whales in the Chukchi Sea during exposure to geophysical exploration sounds from a vessel using an air gun source at a distance of 20 miles. Behaviors included a cow nursing a calf. Peak levels were estimated to be approximately 150 dB re 1 μPa at the location of the whales.

V. <u>Mitigating Measures</u>

The measurements of noise of the eighteen platforms of this study show large variations in noise among the various platforms. This suggests that there are certain combinations of platform construction, machinery, type of operation, ocean environment, etc., which tend to make for quieter operations than other combinations. The purpose of this section is to identify those measures which may be used to produce quiet platforms. Since the limited size of the data base, including number and types of platforms, locations, etc., and a lack of detailed data on machinery type, mountings, structures, etc., makes it

impossible to do an adequate job of analyzing the noise source mechanisms and recommending specific mitigating measures at this time, the approach taken in this section is to outline general principles of noise mitigation, and then suggest certain specific measures which appear relevant to certain platforms.

In general, noise reduction involves a combination of three basic approaches: (1) quieting the source, (2) interrupting the transmission path, and (3) isolating the receiver, such as with ear plugs.

Obviously, approaches 1 and 2 are the only ones available in this case. To assist in understanding the source and path relationships on oil platforms, a hypothetical drilling platform is shown in Fig 4 with various possible noise sources and pathways of sound into the water. For most effective noise mitigation in any specific case, the relative contributions of each source--path combination to the total radiated noise should be known. Because of the lack of specific data, a general approach is outlined below.

General Design Features.

1. Location. Where possible, locate noisy operations as distant as possible from areas which have animal populations which might be sensitive to noise.

2. Acoustic Barrier - An acoustically opaque structure of sufficient size may be located to block the path of sound transmission to a sensitive area. This barrier could be an island, peninsula, or other structure which is not in itself an efficient conductor of sound. In general, a body with an acoustical impedance greatly different from that of water is a good reflector of sound, and therefore serves as a barrier. Screens of air bubbles have been used as underwater sound barriers.

3. Damping. Sound transmission through steel structures, such as platform floors, bracing, legs, etc., can be reduced by structural damping. Many techniques are available for this, employing viscous coatings, constrained viscous layers, etc. (Harris, 1979).

4. Reduced Radiating Surface Area. Radiation of sound from a vibrating structure is reduced if the dimensions of the structure are small compared to the wavelength of the sound. This suggests that several small diameter legs would be better than one large diameter leg for platform support.

5. Quiet Machinery. Platform machinery should be selected for quiet performance. Total power of platform machinery should be kept to a minimum. One technique is to bring electrical power to the platform via cable from shore generators. Well- balanced machines minimize vibration which may excite structures and be radiated as noise. Where gas turbines or reciprocating engines are needed, effective exhaust mufflers should be used to reduce airborne noise, which may penetrate into the water.

6. Vibration and Noise Isolation. Suitably designed resilient mounts, combined with inertia blocks and decks of high mass (Harris, 1979) can prevent transmission of vibration into the structural members, with subsequent radiation into the sea. Airborne noise from machinery may be confined by surrounding the machine with an acoustically opaque enclosure (Harris, 1979).

Specific Observations

1. High level spectrum line components from exhaust noise were observed in air and water at platforms with unmuffled reciprocating engine exhausts. These were not observed on platforms with mufflers.

2. Platforms with prime power supplied by cable from shore generators appeared to be quieter than most with platform-generated power although there were a few significant exceptions.

3. At the quietest platform measured, a man-made island, activation of a sea-water pump caused a significant increase in underwater noise.

4. Work boats and supply vessels appeared to be the source of the highest noise levels observed in the vicinity of the platforms.

5. Vibration measured on a concrete-filled hollow cylindrical steel leg of an operating platform showed a reduction of nearly 20 dB in the leg vibration at the boat deck relative to the vibration of the same leg at the next deck above.

VI. Conclusions

The following must be considered tentative, as they are derived from a relatively limited body of data from a very small sample of platforms, and from calculations using many assumptions, some of which are not yet validated.

1. Oil and gas platforms produce significant underwater noise covering a fairly wide range of frequencies. The spectra generally have spectrum lines in the low frequency region between 4 and 5000 Hz, with highest level components below 100 Hz. The spectrum at higher frequencies is a continuous, broad band spectrum falling off at high frequencies, with a shape somewhat like ambient sea noise.

2. The sound pressure levels of the highest level components of platform noise measured at a distance of 100 feet are generally in the range of 110 to 130 dB re 1 μPa.

3. Underwater sound from platforms engaged in drilling did not in general exhibit markedly different characteristics from those engaged in production.

4. In general the platform noise was steady, with no major variations apparent during normal drilling and production operations.

5. Certain platforms were observed to be relatively quiet during combined drilling and production operations. This suggest that platforms may be designed and constructed for reduced sound emission.

6. The platforms measured did not produce as much noise as that of the cavitating propellers of supply boats and work boats. Propeller cavitation occurs on the boats during transit at normal and high speeds, and during maneuvering operations, as used in docking, loading, etc.

7. Calculations of detectability of platform noise using the source-path-receiver model indicate that mysticete whales may detect the low frequency line components out to ranges of the order of hundreds of miles under conditions of low ambient noise and excellent sound propagation.

8. Application of the source-path-receiver model to detection of platform noise by animals under conditions representative of three OCS areas in Alaska, Southern California, and Middle Atlantic indicated that in no case would the range be expected to exceed 100 nautical miles; and that 3500, 150, and 150 yards are the more likely ranges for detection by whales in the lower Cook Inlet, Alaska; Santa Barbara, California; and Baltimore Canyon, Middle Atlantic areas respectively. These are ranges for the sounds to be at the threshold of detection; so at greater ranges no response may be expected. At shorter ranges responses to noise are possible, but unlikely until the range is so short that the sound is substantially above the threshold of detectability.

9. It is unlikely that platform noise will interfere with echolocation by marine mammals, which occurs mainly at ultrasonic frequencies. At these frequencies the platforms radiate but little noise, and it does not propagate efficiently in the water.

10. It is possible that platform noise could produce masking of certain acoustic communication signals used by marine mammals, but such interference is not likely to be serious unless the receiving animal is very close to the platform, and the sending animal is much farther away.

11. Although not measured in this study, data on impulse sounds used in seismic surveying indicate that their peak sound pressure levels are much greater than other sounds normal to oil and gas operations. These sounds, particularly those from explosive sources, may constitute a more hazardous stimulus than any of the others considered in this study.

12. At present not enough information is available about the behavior, tolerance, and adaptability of individual species to evaluate the effect of OCS platforms on marine mammals conclusively. Anecdotal information tends to indicate that the whales either ignore the platforms or easily avoid them without appreciable change in behavior. Smaller cetaceans and pinnipeds may even find an attractive environment around the platforms. Some caution should be applied because without sufficient baseline information and adequate time for studying any long term effects these results cannot be interpreted in the proper perspectives.

13. Factors which, either singly or combined, tend to make a given OCS area sensitive to man-made noise are the following:

a. Animal population with sensitive hearing.

b. Animal population for which the hearing sense fills an essential need in subsistence.

c. Animal population not yet exposed appreciably to man-made noise. (Example: bowhead whale in Beaufort Sea.)

d. Area with very low ambient noise.

e. Area with excellent sound propagation.

14. Various noise mitigation techniques are available in the acoustical engineering literature, and may be employed in platform design and construction in any OCS areas which are predicted to be noise sensitive.

VII. Recommendations

1. Employ the source-path-receiver model to assess potential noise problems for selected OCS development scenarios involving specific locations, noise sources, and seasonal weather conditions. Sound propagation and ambient noise parameters and the receiving animal species should be selected as appropriate to the locale and season.

2. Give careful consideration in terms of animal populations, seasonal activity and acoustic properties of areas before starting seismic survey operations.

3. Avoid use of survey techniques employing explosives in areas inhabited by marine mammals until effects of such explosive sound pressures have been adequately determined.

4. Obtain additional field measurements and recordings on existing platforms of all types. Particular emphasis should be placed on drill ships, jack-up rigs, and monopods, for which no data are yet in hand. Large differences in underwater noise from platform to platform indicate that a broad sampling of many platforms embracing various types of construction, machinery, installation, and types of ongoing operations is needed to attain a reasonable degree of confidence in the sound source level predictions.

5. Conduct measurements of airborne noise, platform vibration, and underwater noise in such a manner that the mechanisms of sound generation and transfer into water can be understood, and the specific transmission paths defined. Such understanding is required to specify engineering procedures for noise control where needed to meet future noise goals.

6. Obtain additional data on critical, least known components of the path and receiver elements of the source-path-receiver model. These include propagation in specific coastal areas of Alaska, such as the Beaufort Sea; and data on hearing capabilities of the great whales, about which virtually no direct data exist.

7. Conduct studies of the behavioral response of various species of marine mammals to noise stimuli. These studies could involve playback of selected sounds, such as tape recordings of sounds emitted from OCS platforms, at carefully controlled levels and for animals in selected settings of location and season. Tape recordings suitable for such studies are available at NOSC.

8. Obtain direct observational data on behavior of various species of marine animals subjected to noise stimuli in the actual vicinity of oil and gas operations. These data should include both initial responses as might occur at a new installation, and responses over a long period as might relate to animals who have had an opportunity to adapt to the sounds. The studies should include two phases:

a. Pre-Development Studies. Conduct interview programs and observation studies, ideally aerially or nautically, to get baseline information in areas where OCS lease sales are proposed. Conduct studies prior to and during exploration and preliminary drilling, and at some time after drilling has been implemented.

b. Post-Development Studies. Individuals who are trained to identify various species of marine mammals should be placed on each platform to be used in the study with adequate instrumentation such as theodolite range-finder, binoculars, log, and identification books. Their only job should be observing and making recordings of marine mammals. Data collected over a long time period including repetitions of various seasonal activities would be very valuable. Data-taking periods should be planned well in advance.

Because of its predictable, seasonal migration, the gray whale (Eschrichtius robustus) would be an ideal subject for a model study in Santa Barbara Channel and could provide reliable yearly comparison. Studies could be conducted at peak migration times (northerly and southerly movements), as well as in-between migration periods. In the Cook Inlet, studies should be conducted when the salmon run is in full swing and again when it is almost over, so this pr omenon can be looked at in relation to the number of beluga whales in the inlet. As information about migration, feeding, and calving is learned, it will become easier to determine optimum sampling time.

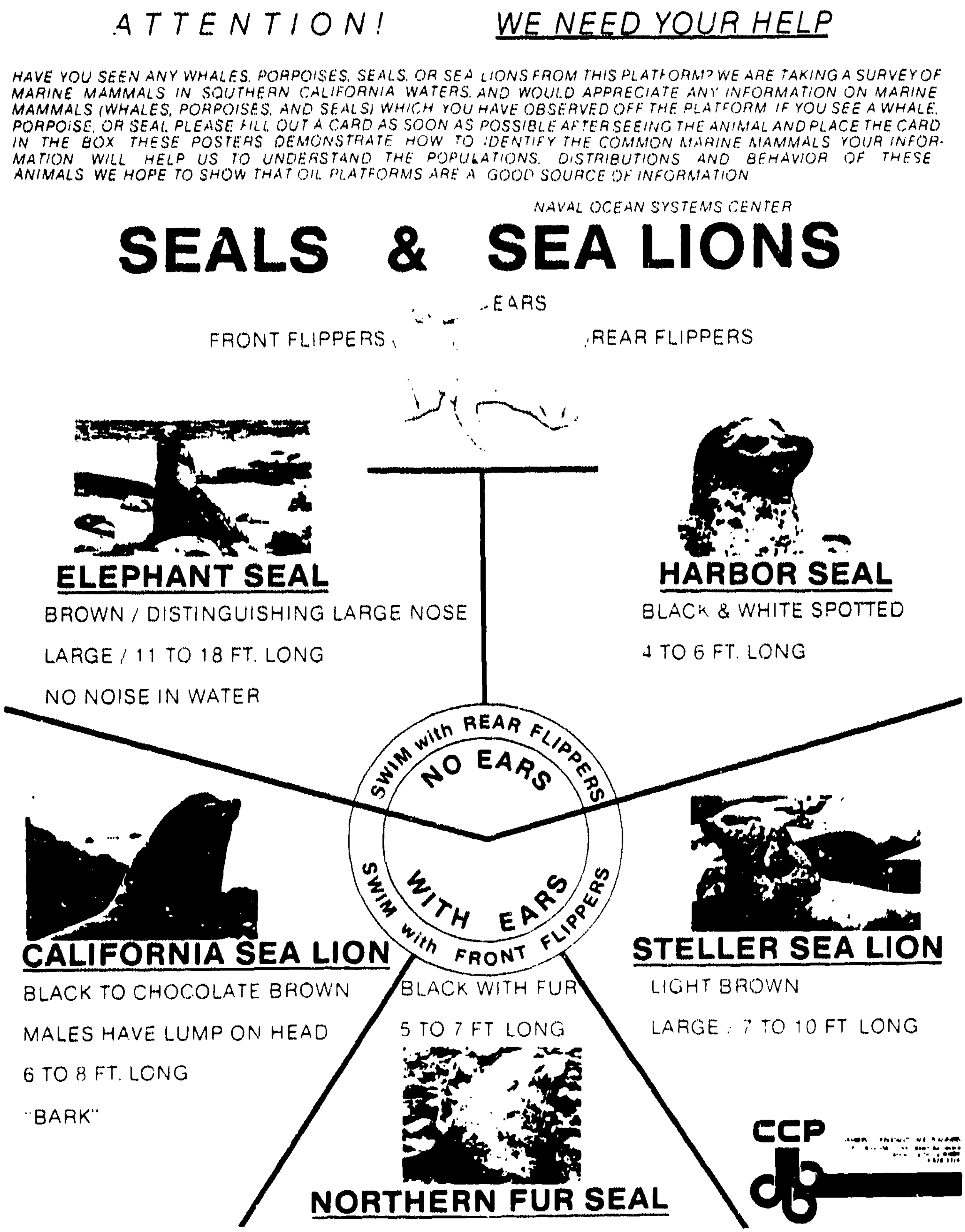

Figure 1. Seals and Sea Lions Identification Poster for Use in Southern California Coastal Areas

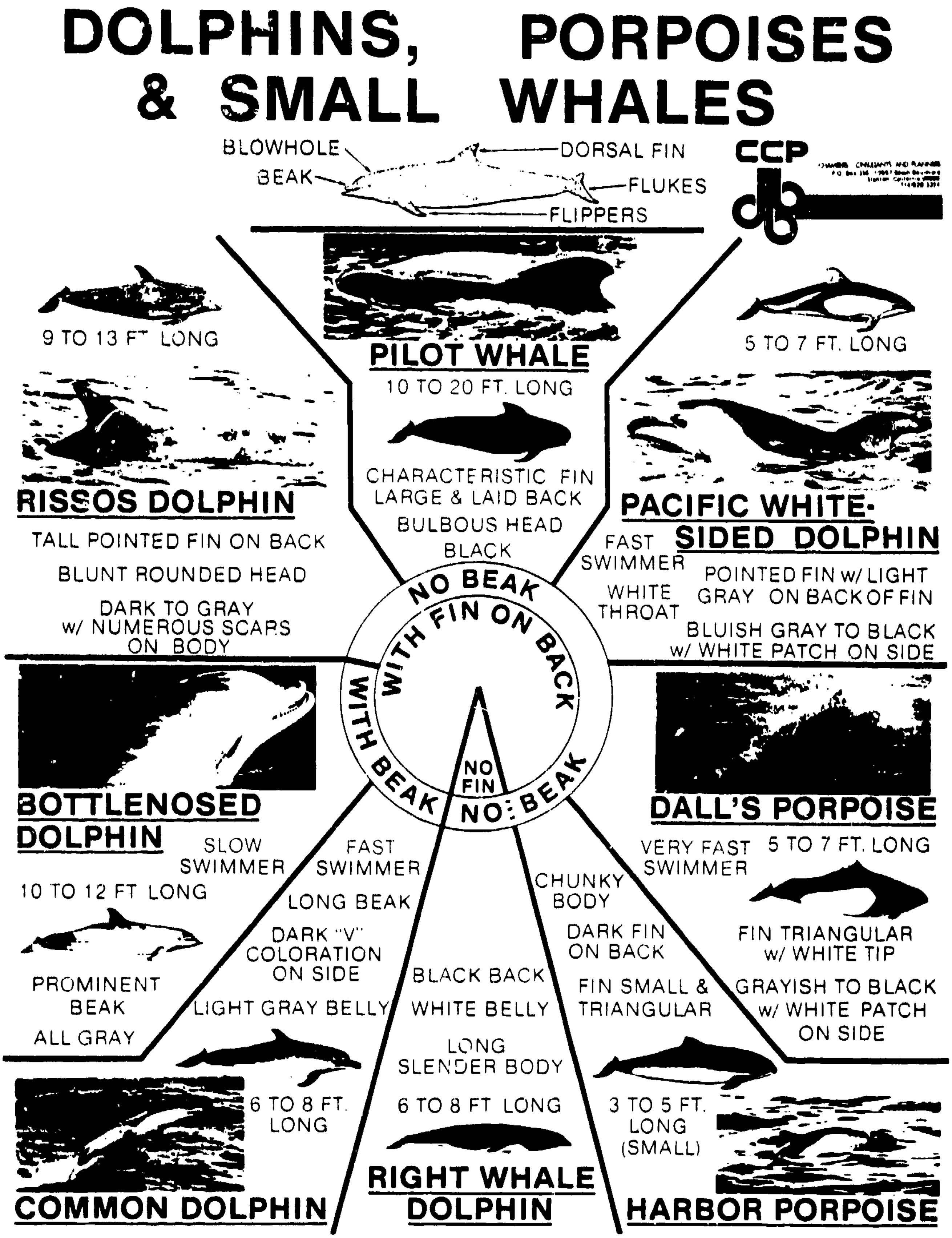

Figure 2. Dolphins, Porpoises, and Small Whales Identification Poster for Use in Southern California Coastal Areas

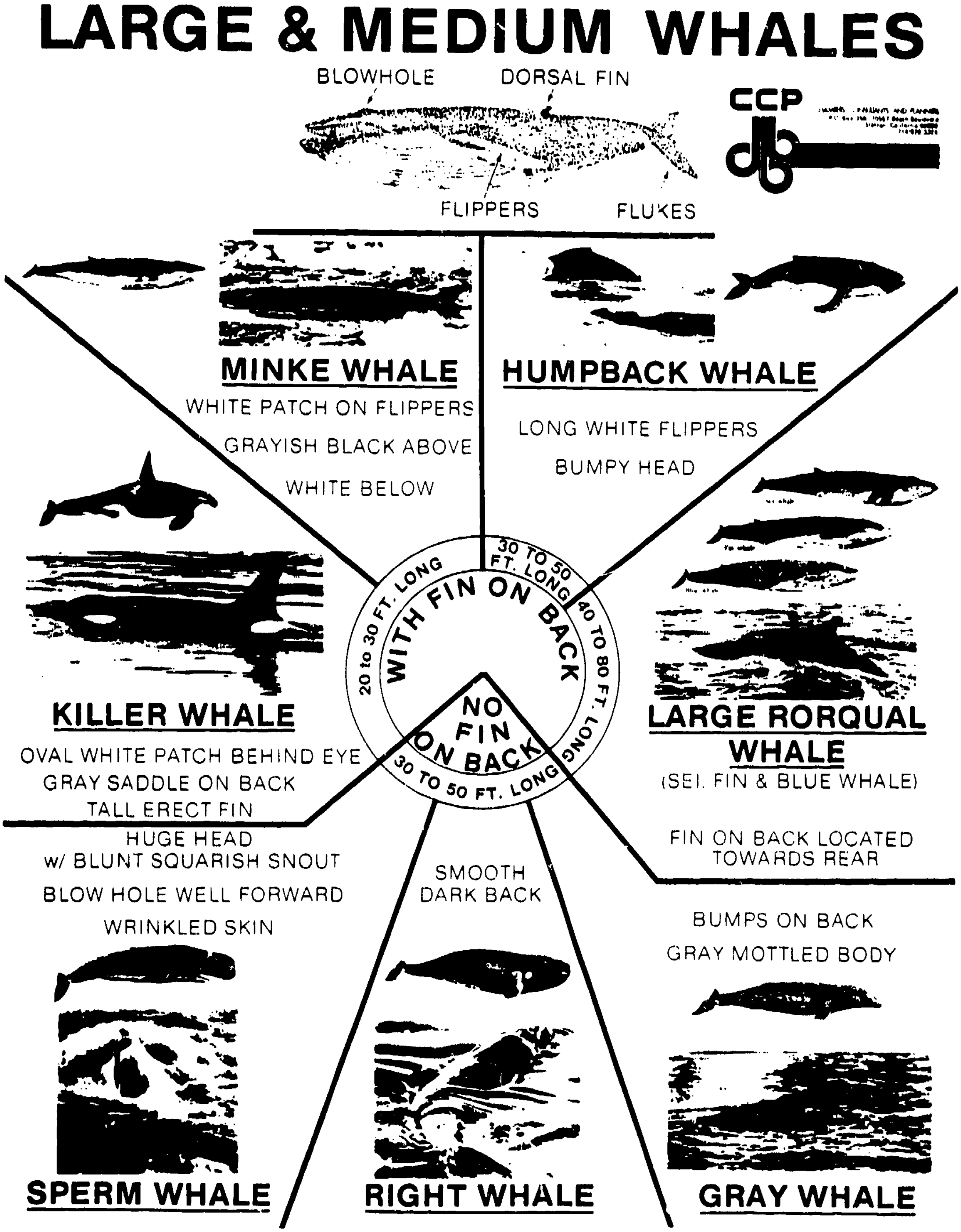

Figure 3. Large and Medium Whales Identification Poster for Use in Southern California Coastal Areas

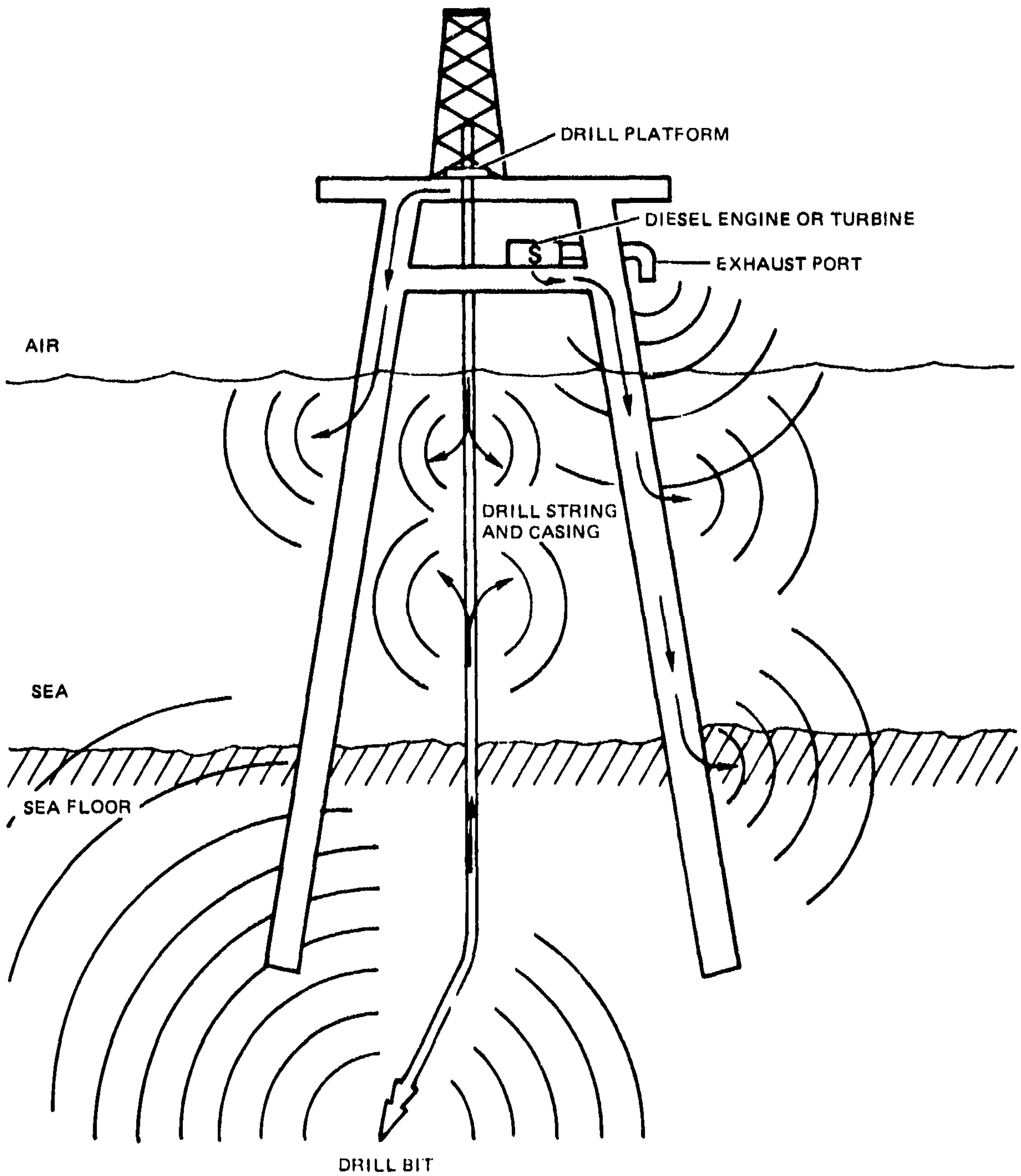

Figure 4. Simplified diagram of hypothetical fixed drilling platform, showing possible sound pathways from source points: diesel engines or turbine, drill platform, and drill bit. Possible paths include: structure-borne, air-borne, drill string and casing-borne, ground-borne, and water-borne sound.

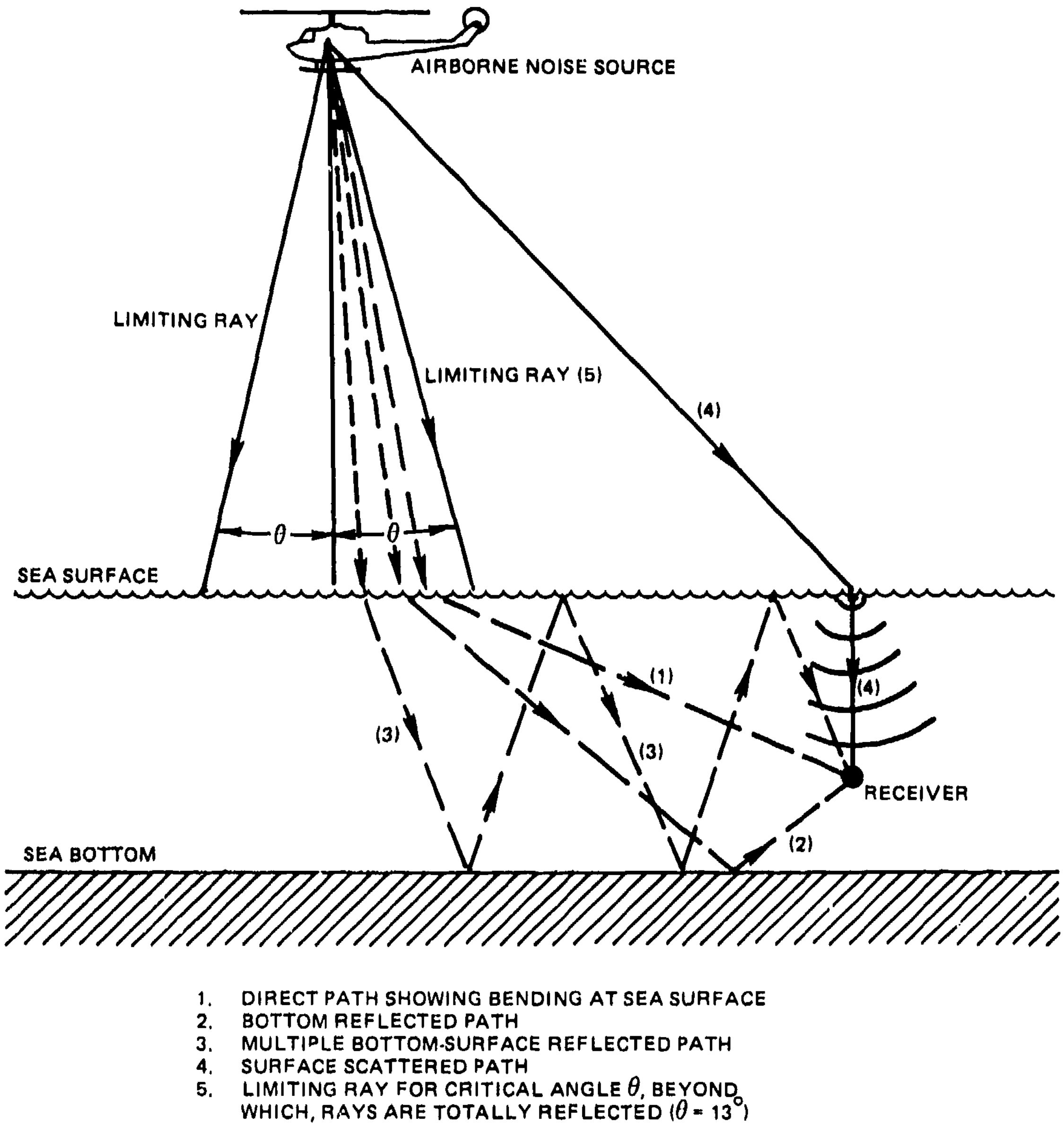

Figure 5. Ray-path diagram showing various air-water propagation paths for helicopter noise (After Urick, 1972)

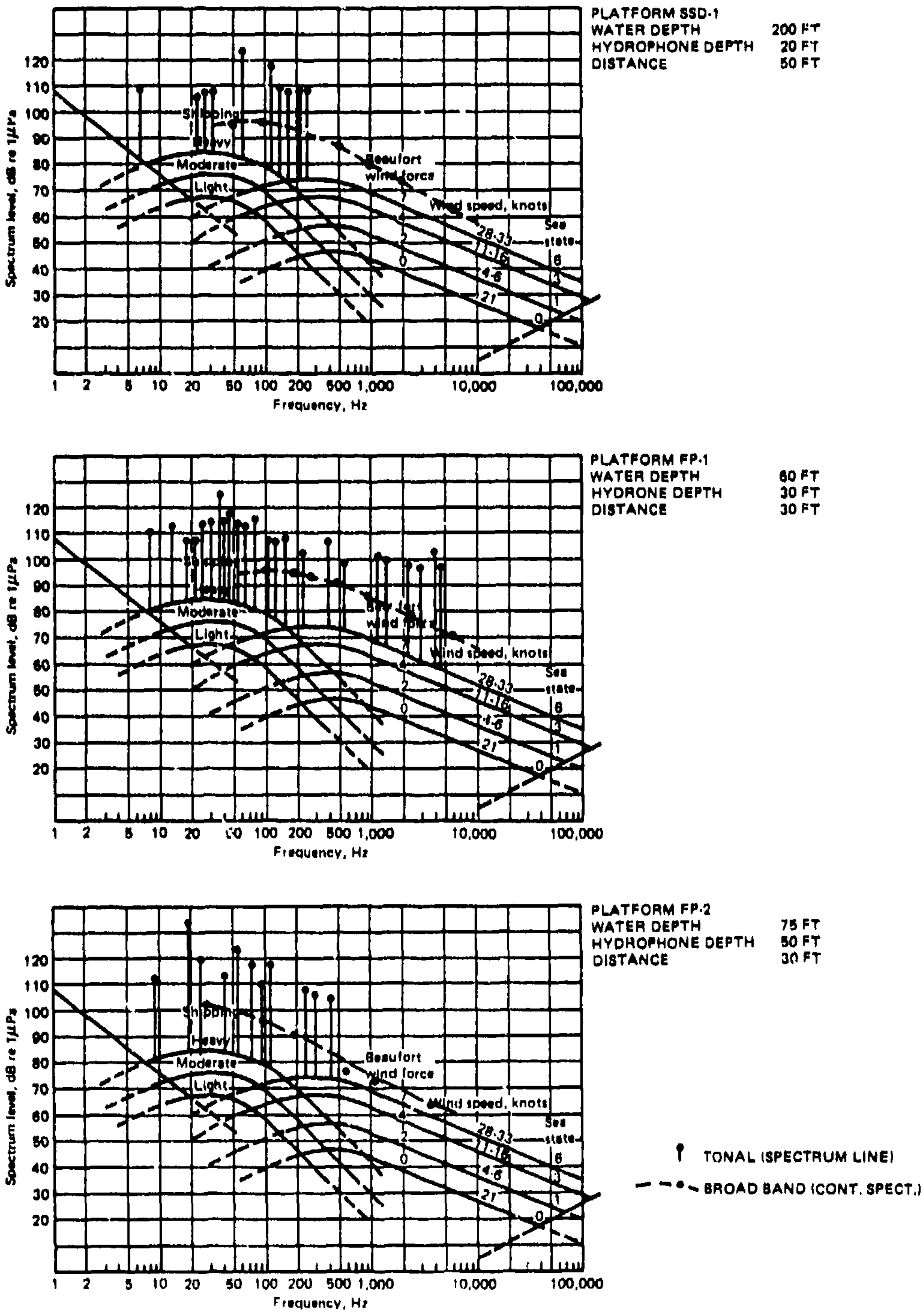

Figure 6. Spectra measured for three Alaska platforms. Spectral lines, also known as tonal components, or tonals, are shown as vertical lines. The continous, or broad-band spectrum is shown as a dashed line with open circles. For reference purposes families of curves showing standard deep sea ambient noise (Urick, 1975) are plotted on each graph.

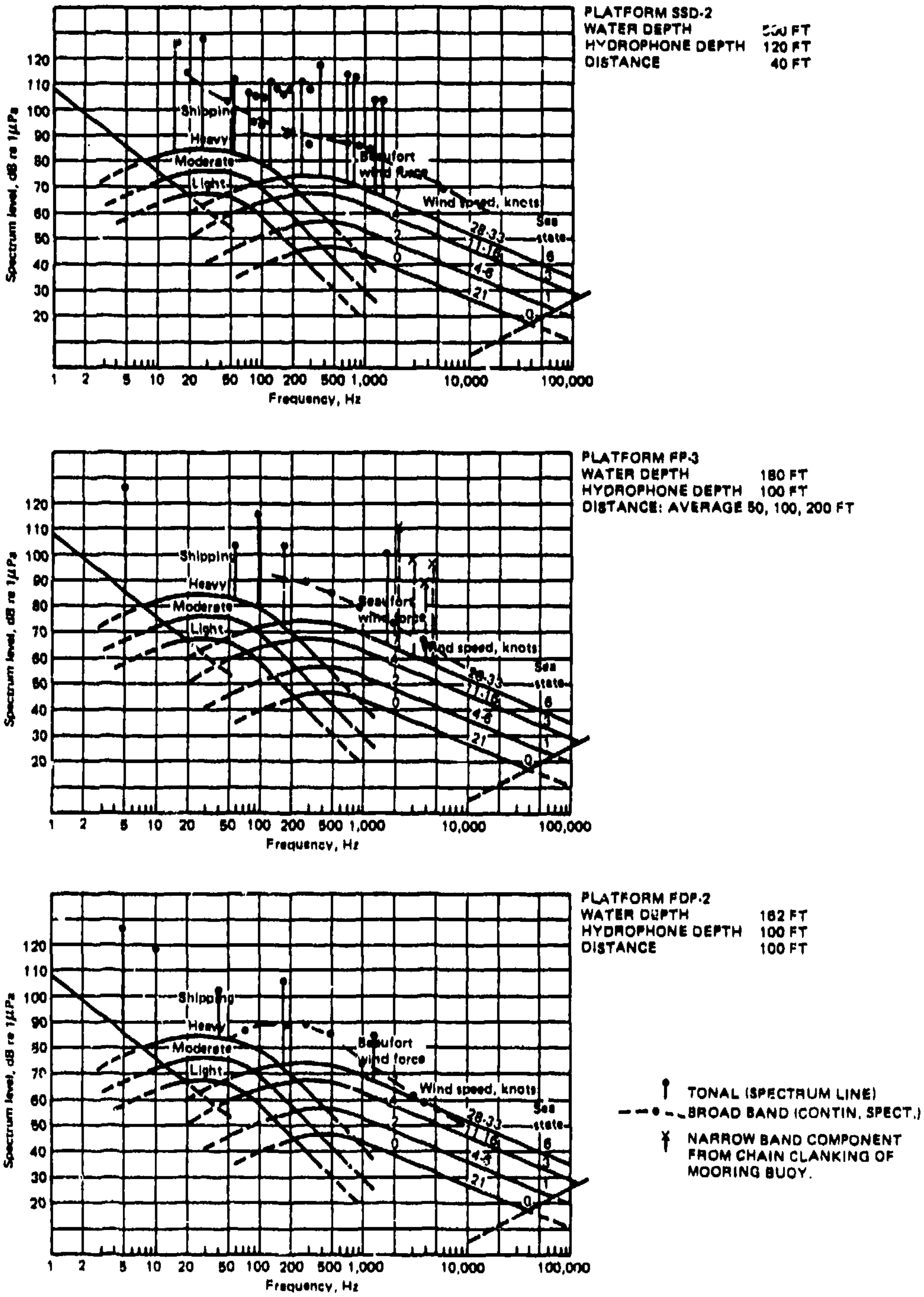

Figure 7. Spectra measured for the Middle Atlantic Platform (SSD-2), and two of the noisier platforms in the Santa Barbara area. Spectral lines also known as tonal components, or tonals, are shown as solid vertical lines. The continuous, or broad-band spectrum is shown as a dashed line with open circles. Tonal components of short duration from a clanking chain are shown as vertical dashed lines. For reference purposes families of curves showing standard deep sea ambient noise (Urick, 1975) are plotted on each graph.

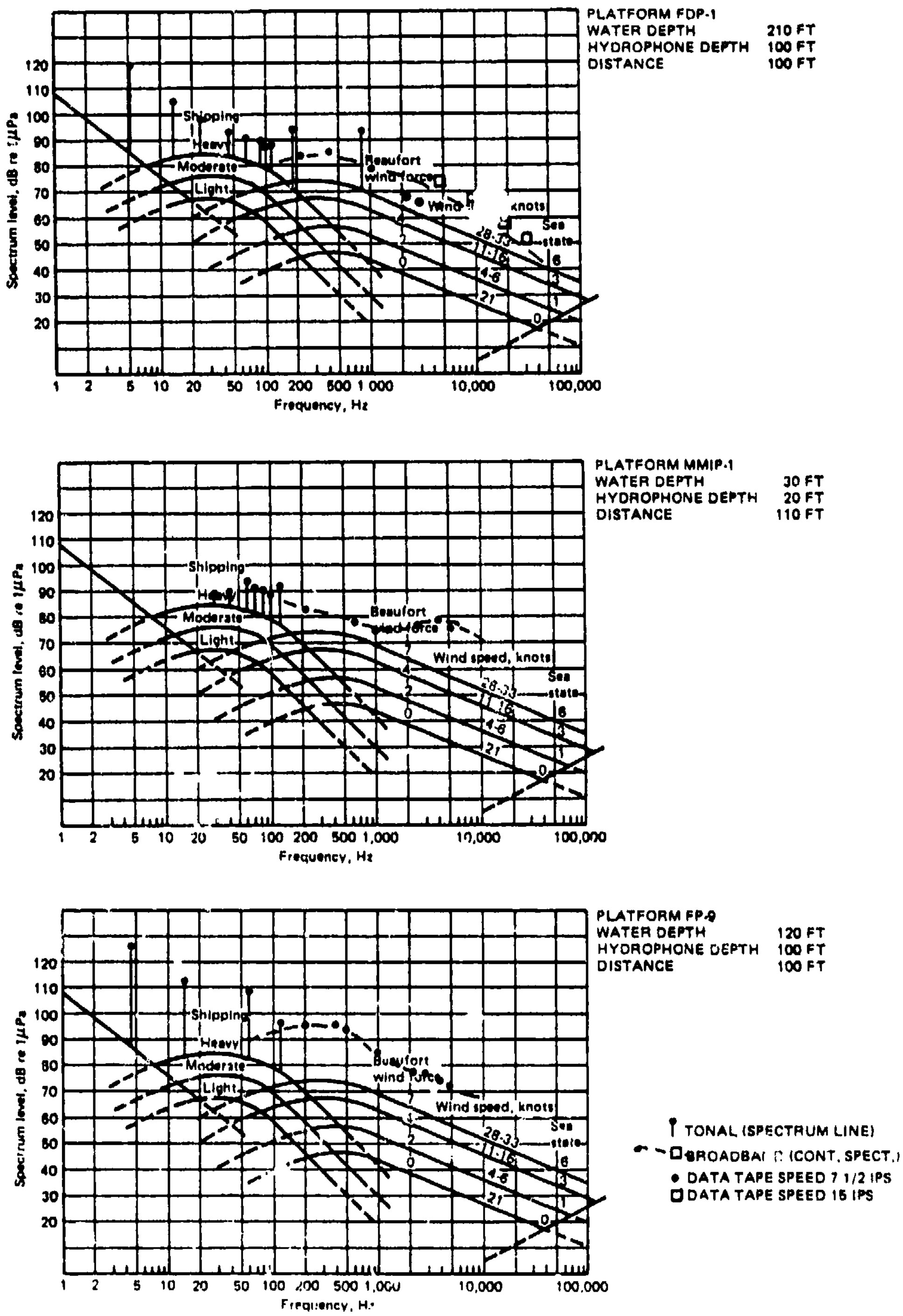

Figure 8. Spectra measured for the three platforms rated quietest. All are from the Santa Barbara area. Spectral lines, also known as tonal components, or tonals, are shown as vertical lines. The continuous, or broad-band spectrum is shown as a dashed line with open circles. For reference purposes families of curves showing standard deep sea ambient noise (Urick, 1975) are plotted on each graph.

Table I - Summary of Platforms

Designation*	Type of Platform	Location	Activity	Power Source	Water Depth	Drill Depth	Noise Notes	Noise Rating
SSD-1	Semi-Submersible-Drill	L. Cook Inlet	Drilling	Diesel (2)	200 ft.	8000 ft	Loud unmuffled exhaust stacks	Moderate
SSD-2	Semi-Submersible-Drill	Baltimore C.	Drilling	Diesel	500 ft	15000 ft	Loud unmuffled exhaust stacks	Moderate
FD-1	Fixed-Multileg-Drill	Santa Barbara	Drilling	Diesel	850 ft		Good mufflers	Moderate
FDP-1	Fixed-Multileg-Drill-Production	Santa Barbara	Drill and Production	Diesel and shore electricity	200 ft	900 ft		Quiet
FDP-2	Fixed-Multileg-Drill-Production	Santa Barbara	Drill and 9 Wells Producing	Gas turbines and shore electricity	162 ft			Noisy
FDP-3	Fixed-Multileg-Drill-Production	Santa Barbara	Drill and Production	Gas	132 ft			Moderate
FP-1	Fixed-4 Leg-Production	U. Cook Inlet	Production	Gas turbine	60 ft	N/A		Moderate
FP-2	Fixed-3 Leg-Production	U. Cook Inlet	Production	Gas turbine	75 ft	N/A		Moderate
FP-3	Fixed-Multileg-Production	Santa Barbara	Production (42 wells)	Shore electricity	190 ft.	N/A		Noisy
FP-4	Fixed-Multileg-Production	Santa Barbara	Production (41 wells)	Shore electricity	190 ft.	N/A		Moderate
FP-5	Fixed-Multileg-Production	Santa Barbara	Production (21 wells)	Shore electricity	190 ft.	N/A		Moderate
FP-6	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Gas turbine	190 ft.	N/A		Moderate
FP-7	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Shore electricity	162 ft.	N/A		Moderate
FP-8	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Shore electricity	144 ft.	N/A		Moderate
FP-9	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Gas (turbine)? and Shore electricity	120 ft.	N/A		Quiet
FP-10	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Shore electricity	90 ft.	N/A		Moderate
FP-11	Fixed-Multileg-Production	Santa Barbara	Production (36 wells)	Gas (turbine)?	90 ft.	N/A		Moderate
MMIP-1	Man-Made Island-Production	Santa Barbara	Production (36 wells)	Shore electricity	45 ft.	N/A	Sea water pump	Very Quiet

*Key to designation code..(1) Platforms: F = fixed, SS = Semi-Submersible, MMI = Man-made island.
(2) Activity: D = Drilling, P = Production.
(3) Numeral: Serial number.

Table II. Summary of Platform Noise Ratings

Platform Activity and Designation	Power Source	Noise Excess* (dB) (1) 30 Hz	(2) 30-300 Hz	(3) 300 Hz	Noise Rating** Bands			Overall
Drilling only								
SSD-1	Diesel	24L	37L	31L	Q	M	M	Moderate
SSD-2	Diesel	38L	33L	40L	M	M	N	Moderate
FD-1	Diesel	35L	14L	32L	M	Q	M	Moderate
Drilling and Production								
FDP-1	Diesel and shore elect.	30L	sOL	23L	M	Q	Q	Quiet
FDP-2	Gas turbine and shore elect.	40L	44L	18L	N	N	Q	Noisy
FDP-3	Gas turbine	37L	31L	23B	M	M	Q	Moderate
Production only								
FP-1	Gas turbine	35L	36L	39L	Q	M	M	Moderate
FP-2	Gas turbine	43L	35L	26L	N	M	Q	Moderate
FP-3	Shore elect.	40L	45L	35L	N	N	M	Noisy
FP-4	Shore elect.	43L	22L	28L	N	Q	Q	Moderate
FP-5	Shore elect.	45L	24L	22L	N	Q	Q	Moderate
FP-6	Gas turbine	40L	28L	26L	N	Q	Q	Moderate
FP-7	Shore elect.	42L	24L	25L	N	Q	Q	Moderate
FP-8	Shore elect.	43L	27L	31L	N	Q	Q	Moderate
FP-9	Gas turbine and shore elect.	37L	27L	22B	M	Q	Q	Quiet
FP-10	Shore elect.	40L	30L	29B	N	M	Q	Moderate
FP-11	Gas turbine	43L	39L	29B	N	M	Q	Moderate
MMIP-1	Shore elect.	0	14L	20B	Q	Q	Q	Very quiet

*Noise excess is dB of source above spectrum level of noise of heavy shipping or sea state 6 at distance of 100 feet from source.

**Band noise rating: Noisy (N) is noise excess > 40 dB.
Moderate (M) is noise excess 30 to 39 dB.
Quiet (Q) is noise excess < 30 dB.

Table III. Calculated Detection Ranges for Platform SSD-1

Platform Data: Semi-submersible, drilling, twin hulls, 16 ft. diameter. Prime power - diesel engines. Water depth - 300 feet

Frequency	Source Level (1/3 Octave Band at 1 Yard)
12 Hz	129 dB re 1 micropascal
72 Hz	138
180 Hz	132
250 Hz	125

Case I: Optimal Propagation (Cylindrical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	72 Hz	30 Kyd 15 nm	180 Hz	6.5 Kyd 3.2 nm
2. Medium Ambient	72 Hz	200 Kyd 99 nm	180 Hz	80 Kyd 39 nm
3. Low Ambient	180 Hz	2500 Kyd 1230 nm	180 Hz	800 Kyd 395 nm

Case II: Conservative Propagation (Spherical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	72 Hz	190 yds 0.09 nm	180 Hz	80 yds 0.03 nm
2. Medium Ambient	72 Hz	450 yds 0.22 nm	180 Hz	290 yds 0.14 nm
3. Low Ambient	180 Hz	2400 yds 1.18 nm	180 Hz	1500 yds 0.74 nm

Table IV. Calculated Detection Ranges for Platform FP-1

Platform Data: Fixed, production, four legs, 10 ft. diameter.
Prime power - gas turbine. Water depth - 60 feet

Frequency	Source Level (1/3 Octave Band at 1 Yard)
40 Hz	137 dB re 1 micropascal
630 Hz	124
2000 Hz	118
5000 Hz	117

Case I: Optimal Propagation (Cylindrical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	40 Hz	15 Kyd 7.4 nm	40 Hz	1.5 Kyd 0.74 nm
2. Medium Ambient	40 Hz	120 Kyd 59. nm	40 Hz	12.0 Kyd 5.9 nm
3. Low Ambient	40 Hz	600 Kyd 296. nm	40 Hz	60.0 Kyd 29.6 nm

Case II: Conservative Propagation (Spherical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	40 Hz	130 yds 0.06 nm	40 Hz	40 yds 0.01 nm
2. Medium Ambient	40 Hz	350 yds 0.17 nm	40 Hz	110 yds 0.05 nm
3. Low Ambient	40 Hz	800 yds 0.39 nm	40 Hz	250 yds 0.12 nm

Table V. Calculated Detection Ranges for Platform FP-2

Platform Data: Fixed, production, three legs, 16 ft. diameter.
Prime power - gas turbine. Water depth - 75 feet

Frequency	Source Level (1/3 Octave Band at 1 Yard)
20 Hz	142 dB re 1 micropascal
63 Hz	134
125 Hz	128
250 Hz	124
500 Hz	125
1600 Hz	110

Case I: Optimal Propagation (Cylindrical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	20 Hz	120 Kyd 59 nm	20 Hz	5 Kyd 2.5 nm
2. Medium Ambient	20 Hz	1000 Kyd 490 nm	20 Hz	35 Kyd 17. nm
3. Low Ambient	20 Hz	6000 Kyd 2960 nm	20 Hz	300 Kyd 148. nm

Case II: Conservative Propagation (Spherical Spreading)

	Animal Listening Assumption			
	A. Good Detection (1/3 octave crit. band)		B. Conservative Detection (100 Hz crit. band)	
Ambient Noise Condition	Frequency	Detection Range	Frequency	Detection Range
1. High Ambient	20 Hz	350 yds 0.17 nm	20 Hz	70 yds 0.03 nm
2. Medium Ambient	20 Hz	1000 yds 0.49 nm	20 Hz	200 yds 0.1 nm
3. Low Ambient	20 Hz	3000 yds 1.50 nm	20 Hz	600 yds 0.3 nm

Table VI. Auditory Data from Marine Mammals; Behavioral Measurement Technique (From Appendix I)

Species	Minimum Frequency (Hz)	Maximum Frequency (kHz)	Maximum Sensitivity (dB/kHz, re bar)	Frequency of high Sensitivity (KHz)	Source
Behavioral: Cetacea					
Tursiops truncatus	100	80			Kellogg, 1953
	150	153			Schevill & Lawrence, 1953
	75	150	-55/50	12-115	Johnson, 1966
	2000*	135	-53/20, -54/50		Ljungblad (personal comm.)
	5000*	140	-40/80	10-100	Morozov et al., 1972
Phocoena pnocoena	1000*	150	-55/8.32	4-64	Andersen, 1970
	4000*	190	-40/64	20-94	Sukhoruchenko, 1973
Delphinus delphis	18	106			Belkovich & Solntseva, 1970
Orcinus orca	500*	31	-70/15	10-20	Hall & Johnson, 1972
Inia geoffrensis	1000*	105	-50/30-50	20-60	Jacobs & Hall, 1972
Delphinapterus leucas (female)	1000*	123	-64/30	20-85	White et al., ms.
D.l. (male)	1000*	122	-59/30	20-75	

*Lowest frequency tested

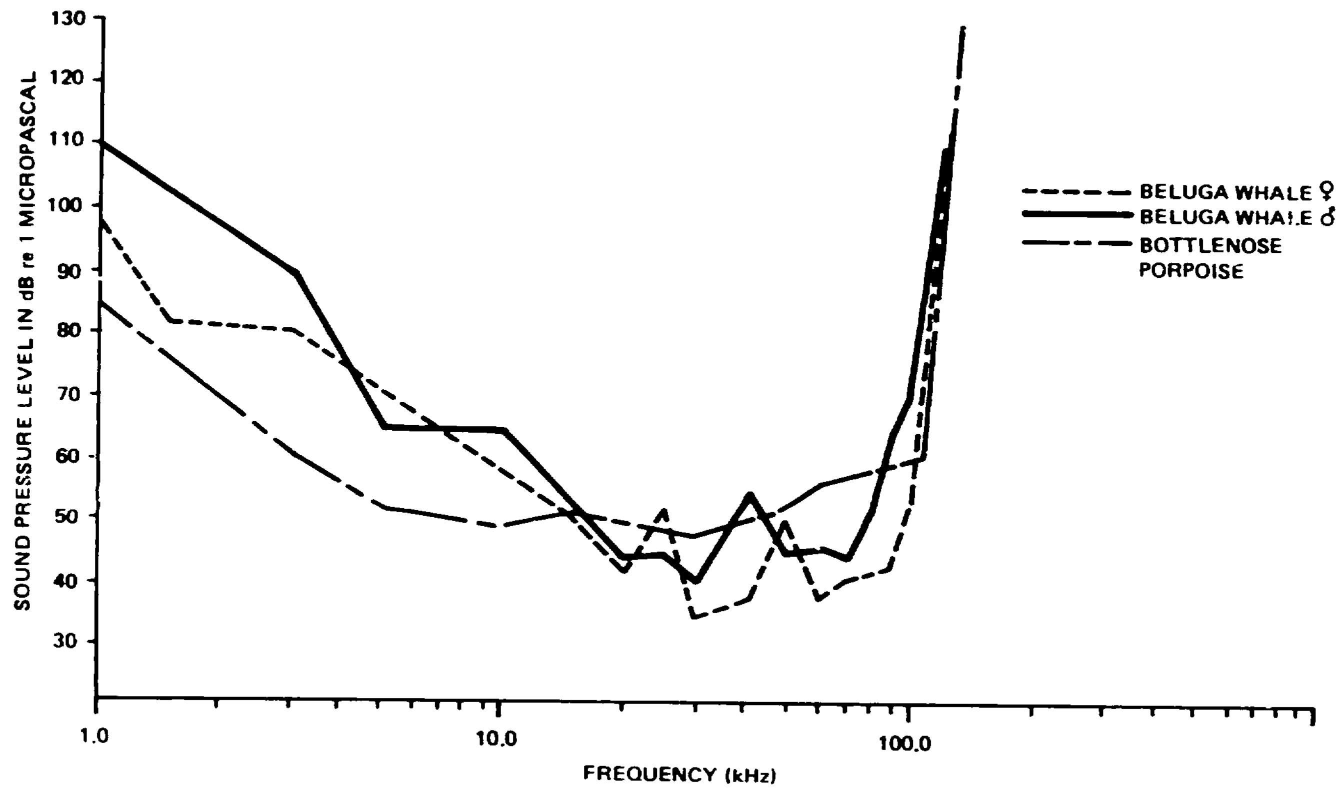

Figure 9. Underwater hearing thresholds for two species of odontocetes, as determined by behavioral methods. Beluga whale male and female, from White et al. (1978). Bottlenose porpoise from Johnson (1966).

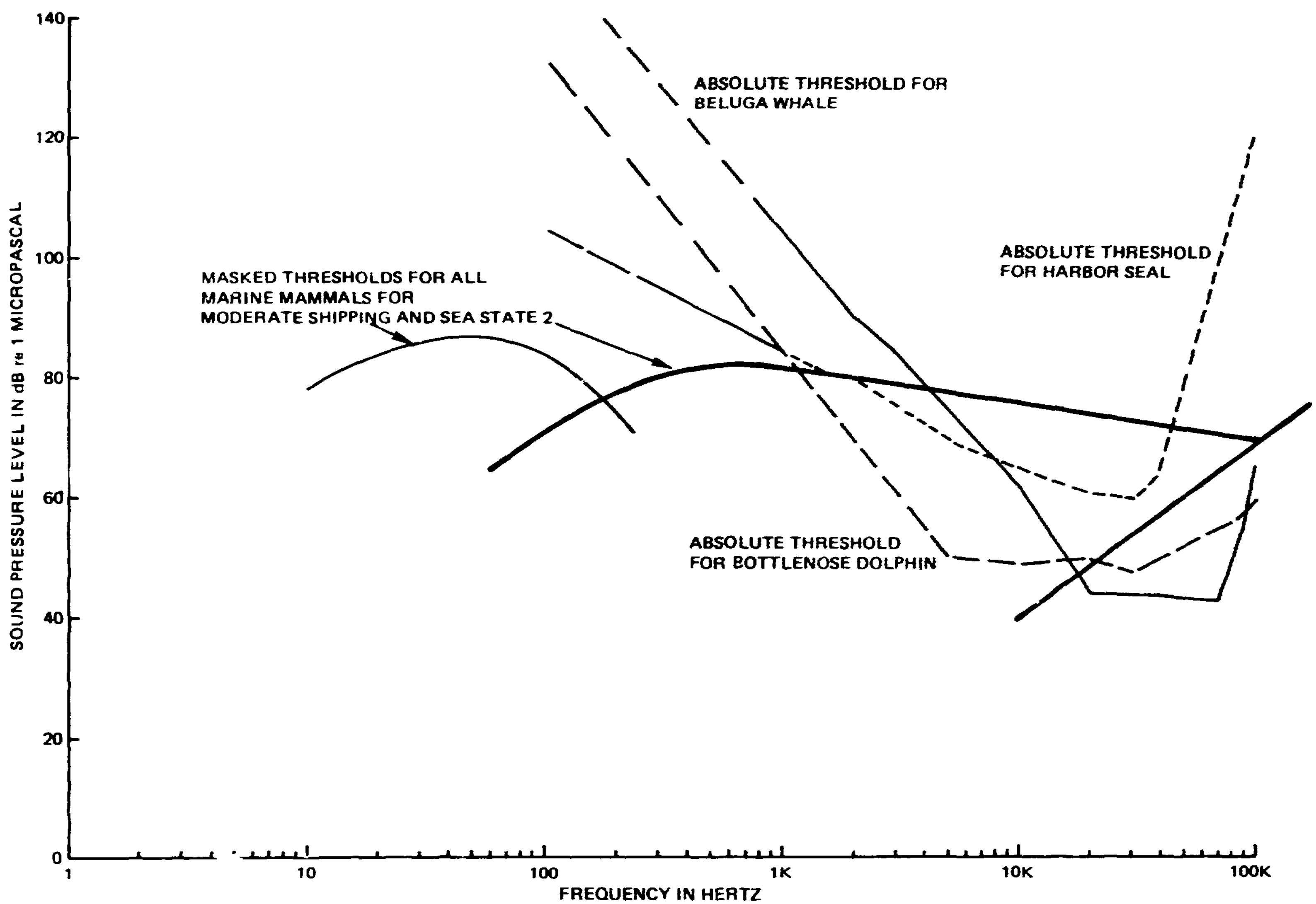

Figure 10. Masked and absolute underwater hearing thresholds for the Beluga Whale, Bottlenose Bolphin, and Harbor Seal. The masked thresholds are for masking by deep sea ambient noise corresponding to moderate shipping density, and sea state 2. Ambient noise data from Urick (1975). Absolute thresholds from Appendix I, Figure 7. Absolute threshold curves below 1 kHz are extrapolations.

Table VII. Summary of Detection Range Calculations for Odontocetes and Pinnipeds

Platform	Frequency	Source 1/3 OB Level	Animal	Abs. Thr.	Masked Thr.-DI	Available Signal	Detection Range	
							Cyl. Spr.	Spher. Spr.
SSD-1	5KHz (BB)	102 dB	Beluga	74 dB	78-5=72 dB	28 dB	600 yds.	25 yds.
			Harbor Seal	70 dB	78-0=78 dB	24 dB	250 yds.	15 yds.
FP-1	5KHz	117 dB	Beluga	74 dB	78-5=73 dB	43 dB	10 Kyd	150 yds.
			Harbor Seal	70 dB	78-0=78 dB	39 dB	6 Kyd	90 yds.
FP-2	5KHz	103 dB	Beluga	74 dB	78-5=73 dB	29 dB	800 yds.	27 yds.
			Harbor Seal	70 dB	78-0=78 dB	25 dB	300 yds.	18 yds.

Table VIII. Summary of Detection Range Calculations for Three Specific OCS Areas

Platform: SSD-1 (Semi-Submersible)

Frequency (Hertz)	Source Level (dB)	Listening Animal	Directivity Index (dB)	Ambient Noise Limit	Minimum Detectable Signal	Available Signal	Propagation Assumption	Detection Range
Alaska, Lower Cook Inlet Area - Spring-Summer-Fall-Waves >5 ft approx. 50% of time. Average wind speed = 15.5 kts (SS-3)								
5000	102	Beluga whale	5	SS-3	78 dB	24 dB	3 dB/dd	250 yds
5000	102	Harbor Seal	0	Mod. shipping	82 dB	20 dB	3 dB/dd	100 yds
72	138	Gray and Fin whales	0	Mod. shipping	85 dB	53 dB	3 dB/dd	200,000 yds (100 nm)
72	138	Gray and Fin whales	0	Mod. shipping	85 dB	53 dB	4.5 dB/dd	3,500 yds (1.8 nm)
California, Santa Barbara, Point Conception Area - Spring-Summer-Fall-Waves >5 ft 50% of time. Average wind speed = 11.7 kts (SS-3)								
72	138	Gray whale	0	SS-3 Heavy shipping	94 dB	44 dB	6 dB/dd	150 yds
72	138	Gray whale	0	SS-3 Heavy shipping	94 dB	44 dB	4.5 dB/dd	900 yds
Middle Atlantic, Baltimore Canyon Area - All-year average - Waves >5 ft 63% of time Average wind speed - 17.0 kts (SS-4)								
72	138	Fin whale	0	SS-4 Heavy shipping	94 dB	44 dB	6 dB/dd	150 yds
72	138	Fin whale	0	SS-4 Heavy shipping	94 dB	44 dB	4.5 dB/dd	900 yds

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